INSTITUTION

OF

MECHANICAL ENGINEERS.

PROCEEDINGS.

1888.

28089

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CORRECTIONS.

Page 228, line 19, omit "*however*"; and this and the six following lines should be corrected to read as follows:—"For his own part he had always objected, when an accurate record was wanted, to deal with a specimen *so small as only* half a square inch in sectional area: *although* that was the size he believed which Sir Joseph Whitworth had depended upon in testing by hydraulic power the quality of the metal for his guns. If a bar of *large* area were tested, the strain could not in his opinion be transmitted equally right through to the centre; *and therefore test pieces of approximate dimensions were essential as a guide in the application of heavy or light sections.*"

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PAST-PRESIDENTS.

George Stephenson, 1847–48. (*Deceased* 1848.)

Robert Stephenson, F.R.S., 1849–53. (*Deceased* 1859.)

Sir William Fairbairn, Bart., LL.D., F.R.S., 1854–55. (*Deceased* 1874.)

Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S., 1856–57, 1866. (*Deceased* 1887.)

John Penn, F.R.S., 1858–59, 1867–68. (*Deceased* 1878.)

James Kennedy, 1860. (*Deceased* 1886.)

The Right Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., 1861–62, 1869.

Robert Napier, 1863–65. (*Deceased* 1876.)

John Ramsbottom, 1870–71.

Sir William Siemens, D.C.L., LL.D., F.R.S., 1872–73. (*Deceased* 1883.)

Sir Frederick J. Bramwell, Bart., D.C.L., F.R.S., 1874–75.

Thomas Hawksley, F.R.S., 1876–77.

John Robinson, 1878–79.

Edward A. Cowper, 1880–81.

Percy G. B. Westmacott, 1882–83.

Sir Lowthian Bell, Bart., F.R.S., 1884.

Jeremiah Head, 1885–86.

Institution of Mechanical Engineers.

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1888.

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Jeremiah Head,	Middlesbrough.
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Percy G. B. Westmacott,	Newcastle-on-Tyne.

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Alfred Bache,

Institution of Mechanical Engineers, 10 *Victoria Chambers, London, S.W.*

[Telegraphic address:—*Mech, London.*]

Institution of Mechanical Engineers.

LIST OF MEMBERS,

WITH YEAR OF ELECTION.[1]

[*Telegraph Address and Telephone No. appended within brackets.*]

1888.

HONORARY LIFE MEMBERS.

1883. Abel, Sir Frederick Augustus, C.B., D.C.L., F.R.S., Royal Arsenal, Woolwich.
1878. Crawford and Balcarres, The Right Hon. the Earl of, F.R.S., 47 Brook Street, Grosvenor Square, London, W.; Haigh Hall, Wigan; and Observatory, Dunecht, Aberdeen.
1888. Haughton, Rev. Samuel, M.D., D.C.L., LL.D., F.R.S., Trinity College, Dublin.
1883. Kennedy, Alexander Blackie William, F.R.S., Professor of Engineering, University College, Gower Street, London, W.C.; and 3 Prince's Street, Westminster, S.W.
1878. Rayleigh, The Right Hon. Lord, F.R.S., 4 Carlton Gardens, London, S.W.; and Terling Place, Witham, Essex.
1888. Rosse, The Right Hon. the Earl of, D.C.L., LL.D., F.R.S., Birr Castle, Parsonstown.

MEMBERS.

1878. Abbott, Thomas, Newark Boiler Works, Newark. [*Abbott, Newark.*]
1883. Abbott, William Sutherland, Locomotive Superintendent and Assistant Engineer, Alagoas Railway, Maceio, Brazil: (or care of George S. Abbott, 9 Disraeli Road, Upton, London, E.)

1861. Abel, Charles Denton, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C. [*Patentable, London.* 2729.]
1874. Abernethy, James, F.R.S.E., 4 Delahay Street, Westminster, S.W.
1876. Adams, Henry, 60 Queen Victoria Street, London, E.C. [*Viburnum, London.*]
1879. Adams, William, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.W.
1848. Adams, William Alexander, Gaines, Worcester.
1881. Adams, William John, 35 Queen Victoria Street, London, E.C. [*Packing, London.* 1854.]
1859. Adamson, Daniel, Engineering Works, Dukinfield, near Manchester; and The Towers, Didsbury, Manchester. [*Adamson, Dukinfield.*]
1871. Adamson, Joseph, Messrs. Joseph Adamson and Co., Hyde, near Manchester. [*Adamson, Hyde.*]
1886. Adamson, Thomas Alfred, 27 Leadenhall Street, London, E.C.
1878. Adcock, Francis Louis, Government Land Surveyor, Main Road, Beaconsfield, Cape Colony: (or care of William R. Adcock, 17 Rue Neuve de Berry, Havre, France.)
1851. Addison, John, Colehill Cottage, Fulham, London, S.W.
1887. Ahmed Bey, Colonel, Imperial Naval Arsenal, Constantinople.
1886. Aisbitt, Matthew Wheldon, 53 Mount Stuart Square, Cardiff. [*Aisbitt, Cardiff.*]
1858. Albaret, Auguste, Engine Works, Liancourt-Rantigny, Oise, France.
1886. Albright, John Francis, Messrs. R. E. Crompton and Co., 4 Mansion House Buildings, Queen Victoria Street, London, E.C.
1885. Alderson, George Beeton, Messrs. Allen Alderson and Co., Alexandria, Egypt; The Lindens, Kew Road, R.O., Richmond, Surrey: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)
1881. Alexander, Edward Disney, care of Mrs. W. Hudson, Middleton Hall, Pickering.
1847. Allan, Alexander, Glen House, The Valley, Scarborough.
1875. Allan, George, New British Iron Works, Corngreaves, near Birmingham; and Corngreaves Hall, near Birmingham.
1885. Allcard, Harry, Messrs. Easterbrook Allcard and Wild, Albert Works, Penistone Road, Sheffield.
1884. Allen, Alfred Evans, 37 Wellington Street, Hull.
1881. Allen, Percy Ruskin, Woodberrie Hill, Loughton, Essex.
1884. Allen, Samuel Wesley, 65 Bute Street, Bute Docks, Cardiff.
1885. Allen, William Henry, Messrs. W. H. Allen and Co., York Street Works, Lambeth, London, S.E. [*Pump, London.*]
1882. Allen, William Milward, Principal Assistant Engineer, Engine Boiler and Employers' Liability Insurance Co., 12 King Street, Manchester.

1870. Alley, John, Malahova, Bekovo Station, Moscow and Riazan Railway, Moscow, Russia: (or care of W. Cuningham, Moscow.)

1877. Alley, Stephen, Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow. [*Alley, Glasgow.* 673.]

1865. Alleyne, Sir John Gay Newton, Bart., Chevin, Belper.

1884. Alleyne, Reynold Henry Newton, Messrs. Scriven and Co., Leeds Old Foundry, Marsh Lane, Leeds.

1872. Alliott, James Bingham, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Ilkeston Road, Nottingham. [*Manloves, Nottingham.*]

1876. Allport, Charles James, Whitehall Club, Parliament Street, Westminster, S.W.

1871. Allport, Howard Aston, Dodworth Grove, Barnsley.

1884. Almond, Harry John, Cartagena and Herrerias Steam Tramways, 43 Muralla del Mar, Cartagena, Spain: (or care of Messrs. G. and W. Almond, 67 Willow Walk, London, S.E.)

1867. Amos, James Chapman, West Barnet Lodge, Lyonsdown, Barnet.

1876. Anderson, Henry John Card, 13 Mount Ararat Road, Richmond, Surrey.

1884. Anderson, Samuel, General Manager, Westbury Iron Works, Westbury, Wiltshire.

1856. Anderson, William, Messrs. Easton and Anderson, Erith Iron Works, Erith, S. O., Kent; Lesney House, Erith, S. O., Kent; and 3 Whitehall Place, London, S.W. [3695.]

1885. Anson, Frederick Henry, 15 Dean's Yard, Westminster, S.W.

1867. Appleby, Charles James, Messrs. Appleby Brothers, 89 Cannon Street, London, E.C. [*Millwright, London.* 1731.]; and East Greenwich Works, London, S.E.

1874. Aramburu y Silva, Fernando, Messrs. Aramburu and Sons, Cartridge Manufacturers, Calle de la Virgen de las Azucenas, Madrid: (or care of Manuel Cardenosa, 86 Great Tower Street, London, E.C.)

1881. Archbold, Joseph Gibson, Messrs. Fawcett Preston and Co., Phœnix Foundry, 17 York Street, Liverpool; and 176 Upper Parliament Street, Liverpool.

1874. Archer, David, Oldbury Railway-Carriage and Wagon Co., Oldbury, near Birmingham; and 275 Pershore Road, Birmingham.

1883. Arens, Henrique, Messrs. Arens and Irmaos, Engineering Works, Rio de Janeiro, Brazil: (or care of Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.)

1882. Armer, James, 52 Cannon Street, London, E.C.; and 13 Clifton Road, Brockley, London, S.E.

1887. Armit, Thomas Napier, Dundee Salvage Co., 23 Panmure Street, Dundee. [*Armit, Dundee.*]

1859. Armitage, William James, Farnley Iron Works, Leeds.

1866. Armstrong, George, Great Western Railway, Locomotive Department, Stafford Road Works, Wolverhampton.

1882. Armstrong, George Frederick, F.R.S.E., Professor of Engineering, The University, Edinburgh.

1876. Armstrong, William, Jun., Mining Engineer, Wingate Colliery, County Durham.

1858. Armstrong, The Right Hon. Lord, C.B., D.C.L., LL.D., F.R.S., Elswick, Newcastle-on-Tyne; and Cragside, Morpeth.

1870. Armstrong, William Irving, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.

1873. Arnold, David Nelson, Messrs. Willans Arnold and Co., Spanish Steel Works, Sheffield.

1879. Arrol, Thomas Arthur, Messrs. Arrol Brothers, Germiston Iron Works, Glasgow; and 18 Blythswood Square, Glasgow. [*Germiston, Glasgow.* 1080.]

1887. Arrol, William, Dalmarnock Iron Works, Glasgow.

1887. Arteaga, Alberto de, 331½ Buen Orden, Buenos Aires, Argentine Republic: (or care of M. Raggio-Carneiro, 129A Winchester House, Old Broad Street, London, E.C.)

1873. Ashbury, Thomas (*Life Member*), 5 Market Street, Manchester; and Ash Grove, Victoria Park, Longsight, Manchester. [*Thomas Ashbury, Manchester.*]

1888. Ashby, George, Tardeo, Bombay, India.

1884. Ashwell, Frank, 10 Erskine Street, Leicester.

1881. Aspinall, John Audley Frederick, Chief Mechanical Engineer, Lancashire and Yorkshire Railway, Horwich, near Bolton; and Fern Bank, Heaton, Bolton.

1877. Astbury, James, Smethwick Foundry, near Birmingham.

1870. Atkinson, Charles Fanshawe, Messrs. Marriott and Atkinson, Fitzalan Steel Works, Sheffield. [*Marriott's, Sheffield.* 174.]

1875. Atkinson, Edward (*Life Member*), Simonds Steel and Iron Forging Works, Acre Street, New Road, Wandsworth Road, London, S.W.

1882. Aveling, Thomas Lake, Messrs. Aveling and Porter, Rochester. [*Aveling, Rochester.*]

1886. Bailey, William, 14 Delahay Street, Westminster, S.W.

1885. Bailey, William Henry, Albion Works, Salford, Manchester. [*Beacon, Salford.*]

1880. Baillie, Robert, Messrs. Westwood Baillie and Co., London Yard Iron Works, Poplar, London, E.

1887. Baillie, Robert Alexander, Messrs. Westwood Baillie and Co., London Yard Iron Works, Poplar, London, E.

1872. Bailly, Philimond, 62 Rue de la Victoire, Paris.

1880. Bain, William Neish, Messrs. Kyle and Bain, Hong Kong Ice Works, Eastpoint, Hong Kong, China; 22 St. Enoch Square, Glasgow; and Collingwood, 7 Aytoun Road, Pollokshields, Glasgow. [*Glacis, Glasgow.*]

1873. Baird, George, St. Petersburg; and Fulmer, Slough.

1887. Baker, William James, 2 New Street, Huddersfield. [*Patent, Huddersfield.*]

1875. Bakewell, Herbert James, Engineer, Department of the Controller of the Navy, Admiralty, Whitehall, London, S.W.

1877. Bale, Manfred Powis, Appold Street, Finsbury, London, E.C.

1884. Balmokand, Lala, Executive Engineer, Public Works Department, Punjaub, India; care of Lala Shamba Das, Said Mitha, Lahore, India.

1887. Bamlett, Adam Carlisle, Agricultural Engineering Works, Thirsk.

1879. Banderali, David, Assistant Locomotive and Carriage Superintendent, Chemin de fer du Nord, Paris.

1888. Baraclough, William Henry, Great Western Buildings, 6 Livery Street, Birmingham.

1885. Barker, Tom Birkett, Scholefield Street, Birmingham.

1884. Barlow, Elias, Messrs. William Muir and Co., Britannia Works, Sherborne Street, Strangeways, Manchester.

1882. Barlow, Henry Bernoulli, 4 Mansfield Chambers, 17 St. Ann's Square, Manchester. [*Monopoly, Manchester.*]

1875. Barlow, William Henry, F.R.S., 2 Old Palace Yard, Westminster, S.W.

1880. Barlow-Massicks, Thomas, Millom Iron Works, Millom, Cumberland.

1881. Barnett, John Davis, Mechanical Superintendent, Grand Trunk Railway, Stratford, Ontario, Canada.

1887. Barningham, James, 27 Corporation Street, Manchester.

1884. Barr, Archibald, Professor of Engineering, Yorkshire College, Leeds.

1878. Barr, James, care of William McConnell, 45 Oakshaw Street, Paisley.

1883. Barras, Harry Haywood, Locomotive Superintendent, Southern Brazilian Rio Grande do Sul Railway, Rio Grande do Sul, Brazil; (or care of George Thomas Barras, 7 Howard Street, Rotherham.)

1879. Barratt, Samuel, Engineer and Manager, Corporation Gas Works, Rochdale Road Station, Manchester.

1882. Barrett, John James, Sewlal Motilal Cotton Mill, Tardeo, Bombay.

1885. Barrie, William, Outside Superintendent Engineer, Nippon Yusen Kaisha Steam Ship Co., Yokohama, Japan.

1887. Barringer, Herbert, Assistant Superintendent Engineer, Messrs. Scrutton Sons and Co., 9 Gracechurch Street, London, E.C.

1862. Barrow, Joseph, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow. [*Shanks, Johnstone.*]

1867. Barrows, Thomas Welch, Messrs. Barrows and Stewart, Portable Engine Works, Banbury. [*Barrows, Banbury.*]

1871. Barry, John Wolfe, 23 Delahay Street, Westminster, S.W. [*Wolfebarry, London.* 3024.]

1883. Bartlett, James Herbert, Standard Building, Montreal, Canada.

1887. Bate, Capt. Charles McGuire, R.E., War Office, Whitehall, London, S.W.

1885. Bateman, Henry, Superintending Engineer, Rangoon Tramways, Rangoon, India.

1881. Bawden, William, Assistant Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1872. Bayliss, Thomas Richard, Adderley Park Rolling Mills and Metal Works, Birmingham; and Belmont, Northfield, Birmingham.

1877. Beale, William Phipson, 12 Old Square, London, W.C.; and 19 Upper Phillimore Gardens, Kensington, London, W.

1887. Beardmore, William, Parkhead Forge and Steel Works, Glasgow.

1880. Beaumont, William Worby, 163 Strand, London, W.C.

1859. Beck, Edward (*Life Member*), Dallam Forge, Warrington; and Springfield, Warrington.

1873. Beck, William Henry, 115 Cannon Street, London, E.C.

1887. Beckwith, George, Engineer, Strand and North Docks Engineering Works, Swansea; and Fairfield House, Mount Pleasant, Swansea.

1875. Beckwith, John Henry, Manager, Messrs. W. and J. Galloway and Sons, Knott Mill Iron Works, Manchester.

1882. Bedson, Joseph Phillips, Messrs. Richard Johnson and Nephew, Bradford Iron Works, Manchester.

1875. Beeley, Thomas, Engineer and Boiler Maker, Hyde Junction Iron Works, Hyde, near Manchester. [*Beeley, Hyde.*]

1884. Beetlestone, George John, 94 St. Mary's Street, Cardiff.

1888. Beldam, Asplan, 77 Gracechurch Street, London, E.C.

1885. Bell, Charles Lowthian, Clarence Iron Works, Middlesbrough.

1858. Bell, Sir Lowthian, Bart., F.R.S., Clarence Iron Works, Middlesbrough; Rounton Grange, Northallerton; and Reform Club, Pall Mall, London, S.W. [*Sir Lowthian Bell, Middlesbrough.*]

1880. Bell, William Henry, Secretary, Stabilimento Armstrong, Pozzuoli, near Naples, Italy.

1879. Bellamy, Charles James, 5 Priory Gardens, Bedford Park, London, W.

1868. Belliss, George Edward, Steam Engine and Boiler Works, Ledsam Street, Birmingham. [*Belliss, Birmingham.*]

1878. Belsham, Maurice, Messrs. Price and Belsham, 52 Queen Victoria Street, London, E.C.

1880. Benham, Percy, Messrs. Benham, 66 Wigmore Street, London, W. [*Benham, London.* 7065.]

1887. Bennetts, Edward John, 1 Dean Villas, Trevu Road, Camborne.

1878. Berrier-Fontaine, Marc, Ingénieur de la Marine, Toulon Dockyard, Toulon, France: (or care of Messrs. P. S. King and Son, Canada Buildings, King Street, Westminster, S.W.) [*Berrier, Toulon.*]

1887. Bertram, William, Messrs. George and William Bertram, St. Katherine's Works, Sciennes, Edinburgh.

1861. Bessemer, Sir Henry, F.R.S., Denmark Hill, London, S.E.

1866. Bevis, Restel Ratsey, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead; and Manor Hill, Birkenhead.

1882. Bewley, Thomas Arthur, Messrs. Bewley Webb and Co., Port of Dublin Ship Yard, Dublin.

1885. Bicknell, Arthur Channing, 42 Pelham Street, South Kensington, London, S.W.

1883. Bicknell, Edward, care of Bank of Bengal, Calcutta, India: (or 8 Canynge Square, Clifton, Bristol).

1884. Bika, Léon Joseph, Locomotive Engineer-in-Chief, Belgian State Railway, 29 Rue des Palais, Bruxelles, Belgium.

1888. Billinton, Robert John, Midland Railway, Locomotive Department, Derby.

1887. Binnie, Alexander Richardson, Town Hall, Bradford.

1877. Birch, Robert William Peregrine, 5 Queen Anne's Gate, Westminster, S.W.

1847. Birley, Henry, 6 Brentwood, Pendleton, R.O., Manchester.

1888. Birtwistle, Richard, Messrs. S. S. Stott and Co., Laneside Foundry, Haslingden, Manchester.

1879. Black, William, Messrs. Black Hawthorn and Co., Gateshead. [*Blackthorn, Newcastletyne.*]

1862. Blake, Henry Wollaston, F.R.S., Messrs. James Watt and Co., 90 Leadenhall Street, London, E.C.

1886. Blandford, Thomas, Corbridge, R.S.O., Northumberland.

1881. Blechynden, Alfred, Naval Construction and Armaments Works, Barrow-in-Furness.

1867. Bleckly, John James, Bewsey Iron Works, Warrington; and Daresbury Lodge, Altrincham.

1882. Blundstone, Samuel Richardson, 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W.

1881. Bocquet, William, North Western Railway, Lahore, India.

1863. Boeddinghaus, Julius, Electrotechniker, Düsseldorf, Germany.

1884. Bone, William Lockhart, Works of the Ant and Bee, West Gorton, Manchester.

1880. Borodin, Alexander, Engineer-in-Chief, Russian South Western Railways, Kieff, Russia.

1888. Borrows, William, Messrs. Edward Borrows and Sons, Providence Foundry, Sutton, St. Helen's, Lancashire.
1885. Boughton, Henry Francis, Dan Rylands, Glass Works, Barnsley; and Hunningley, near Barnsley.
1886. Boult, Alfred Julius, Messrs. W. P. Thompson and Boult, 323 High Holborn, London, W.C.
1888. Boultbee, Frederic Richard, Steam Saw-Mills Department, British Borneo Trading and Planting Co., Sandakan, British North Borneo.
1878. Bourdon, François Edouard, 74 Faubourg du Temple, Paris: (or care of Messrs. Negretti and Zambra, Holborn Viaduct, London, E.C.)
1879. Bourne, William Temple, Messrs. Bourne and Grove, Bridge Steam Saw Mills, Worcester.
1879. Bovey, Henry Taylor, Professor of Engineering, McGill University, Montreal, Canada.
1880. Bow, William, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley. [*Bow, Paisley.*]
1888. Bowen, Edward, Mechanical Engineer and Manager of Workshops, Porto Alegre and New Hamburg Railway, Rio Grande do Sol, Brazil: (or care of Benjamin Packham, 122 Upper Lewes Road, Brighton.)
1870. Bower, Anthony, Messrs. Forrester and Co., Vauxhall Foundry, Vauxhall Road, Liverpool.
1858. Bower, John Wilkes (*Life Member*), Neston, near Chester.
1882. Bowie, Augustus Jesse, Jun., Mining and Hydraulic Engineer, P.O. Drawer 2220, San Francisco, California, United States.
1884. Boyer, Robert Skeffington, 8 Mount Stuart Square, Cardiff.
1882. Bradley, Frederic, Clensmore Foundry, Kidderminster.
1881. Bradley, Thomas, Wellington Foundry, Newark.
1878. Braithwaite, Charles C., 35 King William Street, London Bridge, London, E.C.
1875. Braithwaite, Richard Charles, Messrs. Braithwaite and Kirk, Crown Bridge Works, Westbromwich; and Norfolk House, Handsworth, R. O., Birmingham. [*Braithwaite, Westbromwich.*]
1854. Bramwell, Sir Frederick Joseph, Bart., D.C.L., F.R.S., 5 Great George Street, Westminster, S.W. [*Wellbram, London.* 3060.]
1888. Bratt, Augustus Hicks Henery, 61 Bedford Terrace, Plumstead.
1885. Brearley, Benjamin J., Union Plate Glass Works, St. Helen's.
1868. Breeden, Joseph, New Mill Works, Fazeley Street, Birmingham. [*Breeden, Birmingham.*]
1883. Bricknell, Augustus Lea, 56 Arlington Road, Brixton, London, S.W.
1887. Brier, Henry, Scotch and Irish Oxygen Co., Rosehill Works, Polmadie, Glasgow.

1881. Briggs, John Henry, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.; and Howden.

1886. Bright, William, Manager, Fairwood Tin-Plate Works, Gowerton, R.S.O., Glamorganshire.

1865. Brock, Walter, Messrs. Denny and Brothers, Engine Works, Dumbarton.

1879. Brodie, John Shanks, Town Surveyor and Harbour Engineer, Town Hall, Whitehaven.

1852. Brogden, Henry (*Life Member*), Hale Lodge, Altrincham, near Manchester.

1884. Brook-Fox, Frederick George, Executive Engineer, South Indian Railway, Cuddalore, Madras Presidency, India: (or care of Messrs. H. S. King and Co., 65 Cornhill, London, E.C.)

1880. Brophy, Michael Mary, Messrs. James Slater and Co., 251 High Holborn, London, W.C.

1874. Brotherhood, Peter, 15 and 17 Belvedere Road, Lambeth, London, S.E.; and 94 Cromwell Road, South Kensington, London, S.W. [*Brotherhood, London.*]

1866. Brown, Andrew Betts, F.R.S.E., Messrs. Brown Brothers and Co., Rosebank Iron Works, Edinburgh.

1885. Brown, Benjamin, Widnes Foundry, Widnes.

1879. Brown, Charles, Palazzo Fiodo, Via Nuova Tasso, Naples, Italy: (or care of Dr. Gardiner Brown, 9 St. Thomas' Street, London Bridge, London, S.E.)

1880. Brown, Francis Robert Fountaine, Mechanical Superintendent, Canadian Pacific Railway, Montreal, Canada.

1888. Brown, Frederick Gills, Messrs. Brown and David, Australian Chambers, Queen Street, Brisbane, Queensland; and care of Commissioner, Australian Irrigation Colonies, 35 Queen Victoria Street, London, E.C.

1881. Brown, George William, Messrs. Huntley Boorne and Stevens, Reading Tin Works, Reading.

1863. Brown, Henry, 13 Summer Row, Birmingham.

1887. Brown, James, Sir W. G. Armstrong Mitchell and Co., Elswick Engine Works, Newcastle-on-Tyne.

1884. Brown, Oswald, 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W. [*Acqua, London.*]

1888. Brown, William, Messrs. W. Simons and Co., London Works, Renfrew.

1887. Browne, Frederick John, 69 Lombard Street, London, E.C.

1874. Browne, Tomyns Reginald, District Locomotive Superintendent, East Indian Railway, Asansol, Bengal, India; care of Messrs. W. Watson and Co., 27 Leadenhall Street, London, E.C.

1874. Bruce, Sir George Barclay, 2 Westminster Chambers, 3 Victoria Street, Westminster, S.W.

1867. Bruce, William Duff, Vice-Chairman, Port Commission, Calcutta; and 8 Champion Park, Denmark Hill, London, S.E.

1888. Bruff, Charles Septimus, Assistant Engineer, Nizam's State Railway, Secunderabad, Deccan, India: (or care of E. W. M. Hughes, Balfunning, Sutherland Crescent, Helensburgh.)

1873. Brunel, Henry Marc, 23 Delahay Street, Westminster, S.W. [3024.]

1870. Brunlees, Sir James, F.R.S.E., 12 Victoria Street, Westminster, S.W.

1887. Brunton, Philip George, Resident Engineer, Department of Roads and Bridges, Public Works Office, Sydney, New South Wales: (or care of J. D. Brunton, 19 Great George Street, Westminster, S.W.)

1884. Bryan, William B., Engineer, East London Water Works, Old Ford, London, E.

1888. Bryce-Douglas, Archibald Douglas, Naval Construction and Armaments Works, Barrow-in-Furness.

1873. Buckley, Robert Burton, Executive Engineer, with Supreme Government of India: (or care of H. Burton Buckley, 1 St. Mary's Terrace, Paddington, London, W.)

1877. Buckley, Samuel, Messrs. Buckley and Taylor, Castle Iron Works, Oldham.

1886. Buckney, Thomas, Messrs. E. Dent and Co., 61 Strand, London, W.C.

1887. Buckton, Walter, 27 Ladbroke Square, London, W.

1878. Buddicom, Harry William, Plas-Derwen, Abergavenny.

1872. Budenberg, Arnold, Messrs. Schaeffer and Budenberg, 1 Southgate, St. Mary's Street, Manchester. [*Manometer, Manchester.* 899.]

1882. Budge, Enrique, Engineer-in-Chief, Harbour Works, Valparaiso, Chile: (or care of Messrs. Rose-Innes and Co., 90 Cannon Street, London, E.C.)

1881. Bulkley, Henry Wheeler, 149 Broadway, New York.

1884. Bullock, Joseph Henry, General Manager, Pelsall Coal and Iron Works, near Walsall.

1882. Bulmer, John, Spring Garden Engineering Works, Pitt Street, Newcastle-on-Tyne.

1884. Bunning, Charles Ziethen, 4 Sydney Street, Chelsea, London, S.W.

1884. Bunt, Thomas, Superintendent Engineer, Kiangnan Arsenal, Shanghai, China: (or care of R. Pearce, Lanarth House, Holders Hill, Hendon, London, N.W.)

1884. Bunting, George Albert, Rio Tinto Mines, Huelva, Spain.

1885. Burder, Walter Chapman, Messrs. Messenger and Co., Loughborough.

1877. Burgess, James Fletcher, 14 Almeric Road, Clapham Junction, London, S.W.

1881. Burn, Robert Scott, Oak Lea, Edgeley Road, near Stockport.

1878. Burnett, Robert Harvey, 5 Westminster Chambers, 9 Victoria Street, Westminster, S.W.

1878. Burrell, Charles, Jun., Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford. [*Burrell, Thetford.*]

1885. Burrell, Frederick John, Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford. [*Burrell, Thetford.*]

1887. Burstal, Edward Kynaston, Engineer to the Corporation of Oxford, Corporation Water Works, Oxford.

1877. Burton, Clerke, 22 Oakfield Street, Roath, Cardiff.

1884. Butcher, Joseph John, Edge Moor Iron Works, Post Office, Wilmington, Delaware, United States.

1882. Butler, Edmund, Kirkstall Forge, near Leeds. [*Forge, Kirkstall.*]

1888. Butter, Frederick Henry, Carriage Department, Royal Arsenal, Woolwich; and 4 Hanover Road, Brookhill Park, Plumstead.

1887. Caiger, Emery John, Messrs. W. J. Helmore and Co., 23 St. Mary Axe, London, E.C.

1886. Cambridge, Henry, Messrs. Jacobs and Cambridge, Bute Docks, Cardiff.

1877. Campbell, Angus, Superintendent of the Government Foundry and Workshops, Roorkee, India.

1880. Campbell, Daniel, Messrs. Campbell and Schultz, 90 Cannon Street, London, E.C. [*Duke, London.* 1893.]

1869. Campbell, James, Hunslet Engine Works, Leeds. [*Engineco, Leeds.*]

1882. Campbell, John, Messrs. R. W. Deacon and Co., Kalimaas Works, Soerabaya, Java: (or care of R. Campbell, Slamat Cottage, Mount Vernon, Glasgow.)

1882. Campos, Raphael Martinez, 598 General Lavalle, Buenos Aires, Argentine Republic.

1885. Capito, Charles Alfred Adolph, Messrs. Capito and Hardt, Metropolitan Buildings, 63 Queen Victoria Street, London, E.C.; 9 Belgrave Terrace, Lee, London, S.E.; and 7 Nygade, Copenhagen. [*Capito Hardt, London.*]

1860. Carbutt, Edward Hamer, 19 Hyde Park Gardens, London, W.

1878. Cardew, Cornelius Edward, Locomotive and Carriage Superintendent, Indian State Railway Establishment; care of Messrs. King King and Co., Bombay, India: (or care of Rev. J. H. Cardew, Wingfield Rectory, Trowbridge.)

1875. Cardozo, Francisco Corrêa de Mesquita (*Life Member*), Messrs. Cardozo and Irmâo, Pernambuco Engine Works, Pernambuco, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)

1878. Carlton, Thomas William, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C. [1618.]; and 1 Canfield Gardens, Priory Road, West Hampstead, London, N.W.

1887. Carlyle, Thomas, Inspector of Ordnance Machinery, Royal Artillery, Singapore: (or 72 Glyndon Road, Plumstead.)

1869. Carpmael, Frederick, 106 Croxted Road, West Dulwich, London, S.E.

1866. Carpmael, William, 24 Southampton Buildings, London, W.C. [*Carpmael, London.* 2608.]

1877. Carr, Robert, Resident Engineer, London and St. Katharine Docks Co., London Docks, Upper East Smithfield, London, E.

1884. Carrick, Henry, Messrs. Carrick and Wardale, Redheugh Engine Works, Gateshead; and Holly House, Gateshead. [*Wardale, Gateshead.*]

1888. Carrick, Samuel Stewart, Superintendent Engineer, Shaw Savill and Albion Steamship Co., 34 Leadenhall Street, London, E.C.

1874. Carrington, William T. H., 72 Mark Lane, London, E.C.

1877. Carter, Claude, Manager, Messrs. Hetherington and Co., Ancoats Works, Pollard Street, Manchester.

1885. Carter, Herbert Fuller, La Compañia Unida, Guanajuato, Mexico: (or care of H. M. Carter, 1 Gresham Buildings, Basinghall Street, London, E.C.)

1877. Carter, William, Manager, The Hydraulic Engineering Company, Chester.

1870. Carver, James, Lace Machine Works, Alfred Street, Nottingham.

1888. Castle, Frank, Normal School of Science, South Kensington, London, S.W.

1883. Cawley, George, 70 Market Street, Manchester.

1876. Challen, Stephen William, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham. [*Derwent, Birmingham.*]

1886. Chalmers, John Reid, 52 Amwell Street, Claremont Square, London, E.C.

1884. Chamberlain, John, Metropolitan Gas Works, West Melbourne, Melbourne, Victoria: (or care of J. Chamberlain, 188 West Ferry Road, Millwall, Poplar, London, E.)

1887. Chapman, Alfred Crawhall, 2 St. Nicholas' Buildings, Newcastle-on-Tyne.

1888. Chapman, Arthur, Messrs. Marillier and Edwards, 1 Hastings Street, Calcutta, India.

1882. Chapman, Hedley, Messrs. Chapman Carverhill and Co., Scotswood Road, Newcastle-on-Tyne.

1866. Chapman, Henry, 69 Victoria Street, Westminster, S.W.; and 10 Rue Laffitte, Paris.

1878. Chapman, James Gregson, Messrs. Fawcett Preston and Co., Phœnix Foundry, Liverpool; and 25 Austinfriars, London, E.C. [*Fawcett, London.*]

1885. Chapman, John, Engineer, Windsor and Eton Water Works, Eton.

1887. Chapman, Joseph Crawhall, 70 Chancery Lane, London, W.C.

1885. Charnock, George Frederick, Engineering Department, Technical College, Bradford.

1877. Chater, John, Messrs. Henry Pooley and Son, 89 Fleet Street, London, E.C.

1887. Chatwin, James, Victoria Works, Great Tindal Street, Ladywood, Birmingham.

1872. Chatwin, Thomas, Victoria Works, Great Tindal Street, Ladywood, Birmingham. [*Chatwin, Birmingham.*]

1867. Chatwood, Samuel, Lancashire Safe and Lock Works, Bolton; and Irwell House, Drinkwater Park, Prestwich, near Manchester.

1873. Cheesman, William Talbot, Hartlepool Rope Works, Hartlepool.

1881. Chilcott, William Winsland, Devonport Dockyard, Devonport.

1877. Chisholm, John, Messrs. William Muir and Co., Sherborne Street, Manchester; and 30 Devonshire Street, Higher Broughton, Manchester.

1886. Chittenden, Edmund Barrow, Messrs. Chittenden Knight and Co., Sittingbourne; and Manor House, Offham, West Malling, near Maidstone.

1857. Chrimes, Richard, Messrs. Guest and Chrimes, Brass Works, Rotherham.

1888. Chubb, Thomas Lyon, Ferro Carril del Sud, Buenos Aires, Argentine Republic.

1880. Churchward, George Dundas, Locomotive Superintendent, China Railway Company, care of H.B.M.'s Consulate, Tientsin, North China: (or care of A. W. Churchward, London Chatham and Dover Railway, Queenborough Pier, Queenborough.)

1871. Clark, Christopher Fisher, Mining Engineer, Garswood Coal and Iron Co., Park Lane Collieries, Wigan; and Cranbury Lodge, Park Lane, Wigan. [*Park Lane, Wigan.*]

1878. Clark, Daniel Kinnear, 8 Buckingham Street, Adelphi, London, W.C.

1867. Clark, George, Southwick Engine Works, near Sunderland.

1869. Clark, William, Mining Engineer, Teversall Collieries, near Mansfield.

1865. Clarke, John, Messrs. Hudswell Clarke and Co., Railway Foundry, Jack Lane, Leeds. [*Loco, Leeds.* 504.]

1869. Clarke, William, Messrs. Clarke Chapman and Gurney, Victoria Works, South Shore, Gateshead.

1870. Clayton, Nathaniel, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln. [*Claytons, Lincoln.*]

1886. Clayton, Samuel, St. Thomas' Engine Works, Sunbridge Road, Bradford.

1882. Clayton, William Wikeley, Messrs. Hudswell Clarke and Co., Railway Foundry, Jack Lane, Leeds. [*Loco, Leeds.* 504.]

1871. Cleminson, James, Dashwood House, 9 New Broad Street, London, E.C. [*Catamarca, London.*]

1873. Clench, Frederick, Messrs. Robey and Co., Globe Iron Works, Lincoln. [*Robey, Lincoln.*]

1885. Close, John, Jun., York Engineering Works, Leeman Road, York.

1885. Clutterbuck, Herbert, 42 Newcomen Street, Redcar.

1882. Coates, Joseph, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1883. Coath, David Decimus, Agricultural Implement Works and Saw Mill, Rangoon, British Burmah, India.

1881. Cochrane, Brodie, Mining Engineer, Aldin Grange, Durham.

1858. Cochrane, Charles, Woodside Iron Works, near Dudley; and Green Royde, Pedmore, near Stourbridge.
1887. Cochrane, George, Resident Engineer, London Hydraulic Power Works, 46 Holland Street, Blackfriars Road, London, S.E.
1885. Cochrane, John, Grahamston Foundry and Engine Works, Barrhead, near Glasgow. [*Cochrane, Barrhead.*]
1869. Cochrane, Joseph Bramah, Woodside Iron Works, near Dudley.
1868. Cochrane, William, Mining Engineer, Elswick Colliery, Elswick, Newcastle-on-Tyne; and Oakfield House, Gosforth, Newcastle-on-Tyne.
1867. Cockey, Francis Christopher, Selwood Iron Works, Frome.
1864. Coddington, William, M.P., Ordnance Cotton Mill, Blackburn; and Wycollar, Blackburn.
1884. Cole, Charles, Messrs. Cole Marchent and Co., Prospect Foundry, Bradford.
1878. Cole, John William, Messrs. James Martin and Co., Phœnix Foundry, Gawler, South Australia: (or care of J. C. Lanyon, 27 Gresham House, Old Broad Street, London, E.C.)
1878. Coles, Henry James, Sumner Street, Southwark, London, S.E.
1886. Coles, Robert, 1 Woodstock Road, Moseley, Birmingham.
1877. Coley, Henry, Mansion House Chambers, Queen Victoria Street, London, E.C.
1884. Collenette, Ralph, 38 Dixon Street, Rotherham.
1888. Colley, Benjamin, Laburnum Villa, Westbromwich.
1884. Colquhoun, James, General Manager, Tredegar Iron Coal and Steel Works, Tredegar.
1884. Coltman, John Charles, Messrs. Huram Coltman and Son, Engineering Works, Meadow Lane, Loughborough.
1878. Colyer, Frederick, 18 Great George Street, Westminster, S.W.
1888. Combe, Abram, Messrs. Combe Barbour and Combe, Falls Foundry, Belfast.
1881. Compton-Bracebridge, John Edward, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.
1888. Constantine, Ezekiel Grayson, 5A New Brown Street, Manchester.
1874. Conyers, William, Engineer, Bluff Harbor Board, Campbelltown, Otago, New Zealand.
1888. Cook, John Joseph, Messrs. Robinson Cooks and Co., Atlas Foundry, St. Helen's, Lancashire.
1877. Cooper, Arthur, North Eastern Steel Co., Royal Exchange, Middlesbrough.
1883. Cooper, Charles Friend, Messrs. Paterson and Cooper, Telegraph Works, Pownall Road, Dalston, London, E. [*Patella, London.* 1140.]
1877. Cooper, George, Pencliffe, Alleyne Road, West Dulwich, London, S.E.
1874. Cooper, William, Neptune Engine Works, Hull. [*Neptune, Hull.*]

1881. Coote, Arthur, Messrs. R. and W. Hawthorn Leslie and Co., Hebburn, Newcastle-on-Tyne.

1881. Copeland, Charles John, Messrs. Westray Copeland and Co., Barrow-in-Furness. [*Engine, Barrow-in-Furness.*]

1885. Coppée, Evence, 223 Avenue Louise, Bruxelles, Belgium.

1884. Corder, George Alexander, 74 Ivydale Road, Nunhead, London, S.E.

1878. Cornes, Cornelius, 6 Norfolk Crescent, Bath, [*Stothert, Cornes, Bath.*]; and 30 Walbrook, London, E.C. [*Stothert, Cornes, London.*]

1848. Corry, Edward, 9 New Broad Street, London, E.C.

1881. Cosser, Thomas, McLeod Road Iron Works, Kurrachee, India: (or care of Messrs. Ironside Gyles and Co., 1 Gresham Buildings, Guildhall, London, E.C.)

1884. Cotton, John, Messrs. E. Ripley and Sons, Bowling Dye Works, Bradford.

1875. Cottrill, Robert Nivin, Beehive Works, Bolton. [*Beehive, Bolton.*]

1887. Coulman, John, Hull and Barnsley Railway, Spring Head Works, Hull.

1868. Coulson, William, High Coniscliffe, Darlington.

1878. Courtney, Frank Stuart, 3 Whitehall Place, London, S.W.; and 76 Redcliffe Square, South Kensington, London, S.W.

1875. Coward, Edward, Messrs. Melland and Coward, Cotton Mills and Bleach Works, Heaton Mersey, near Manchester.

1875. Cowen, Edward Samuel, Messrs. G. R. Cowen and Co., Beck Works, Brook Street, Nottingham; and 9 The Ropewalk, Nottingham. [*Cowen, Nottingham.* 87.]

1870. Cowen, George Roberts, 9 The Ropewalk, Nottingham. [286.]

1880. Cowper, Charles Edward, 6 Great George Street, Westminster, S.W.

1847. Cowper, Edward Alfred, 6 Great George Street, Westminster, S.W.

1878. Coxhead, Frederick Carley, 27 Leadenhall Street, London, E.C.

1887. Crabbe, Alexander, Champdany Jute Works, Serampore, Bengal.

1883. Crampton, George, 14 Victoria Street, Westminster, S.W.

1847. Crampton, Thomas Russell, 14 Victoria Street, Westminster, S.W.

1882. Craven, John, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.

1871. Craven, Joseph, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.

1866. Craven, William, Vauxhall Iron Works, Osborne Street, Manchester.

1884. Crighton, John, Union Engineering Co., 2 Clarence Buildings, Booth Street, Manchester.

1873. Crippin, Edward Frederic, Mining Engineer, Brynn Hall Colliery, Ashton, near Wigan.

1883. Croft, Henry, Chemanns, Vancouver Island.

1878. Crohn, Frederick William, 16 Burney Street, Greenwich, London, S.E.

1877. Crompton, Rookes Evelyn Bell, Arc Works, Chelmsford; and Mansion House Buildings, Queen Victoria Street, London, E.C. [*Crompton, Chelmsford.*]

1884. Crook, Charles Alexander, Telegraph Construction and Maintenance Works, Enderby's Wharf, East Greenwich, London, S.E.

1881. Crosland, James Foyell Lovelock, Chief Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1865. Cross, James, Messrs. John Hutchinson and Co., Alkali Works, Widnes; and Eirianfa, Llangollen.

1871. Crossley, William, 153 Queen Street, Glasgow. [*Crossley, Glasgow.* 584.]

1875. Crossley, William John, Messrs. Crossley Brothers, Great Marlborough Street, Manchester. [*Crossleys, Openshaw.*]

1888. Crowe, George, Albion Chambers, Bute Docks, Cardiff.

1882. Cruickshank, William Douglass, Chief Government Engineer Surveyor, Marine Board, Sydney, New South Wales.

1886. Cryer, Thomas, Mechanical Engineering Department, Manchester Technical School, Princess Street, Manchester; and Urmston, near Manchester.

1875. Curtis, Richard, Messrs. Curtis Sons and Co., Phœnix Works, Chapel Street, Manchester. [*Curtius, Manchester.*]

1887. Cutler, George Benjamin, Messrs. Samuel Cutler and Sons, Providence Iron Works, Millwall, London, E.; and 4 Westcombe Park, Blackheath, London, S.E.

1876. Cutler, Samuel, Messrs. Samuel Cutler and Sons, Providence Iron Works, Millwall, London, E. [*Cutler, Millwall.* 5059.]

1888. Dadabhoy, Cursetjee, Messrs. Shapurji Sorabji and Co., Bombay Foundry and Engine Works, Khetwady, Bombay, India.

1864. Daglish, George Heaton, Rock Mount, St. Anne's Road, Aigburth, near Liverpool. [*Daglish, Aigburth.* 2717.]

1883. D'Albert, Charles, Messrs. Hotchkiss and Co., 6 Route de Gonesse, St. Denis, near Paris; and 16 Rue des Chesneaux, Montmorency, Seine-et-Oise, France.

1886. Dale, Thomas, Townsend Foundry, Kirkcaldy.

1881. D'Alton, Patrick Walter, 49 Bugle Street, Southampton.

1866. Daniel, Edward Freer, Messrs. Worthington and Co., The Brewery, Burton-on-Trent; and 89 Derby Street, Burton-on-Trent.

1866. Daniel, William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds; and Oxford House, Horsforth, Leeds.

1888. Darbishire, James Edward, 110 Cannon Street, London, E.C.

1878. Darwin, Horace (*Life Member*), The Orchard, Huntingdon Road, Cambridge.

1873. Davey, Henry, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds [*Sun Foundry, Leeds*]; and 3 Prince's Street, Westminster, S.W.

1883. Davidson, George, Superintendent Engineer, Australasian Steam Navigation Co., Sydney, New South Wales.

1865. Davidson, James, Crescent Villa, Lower Eglinton Road, Plumstead.

1884. Davidson, James Young, Manager, Nagpur and Chhattisgarh, and Wardha Coal State Railways, Nagpur, Central Provinces, India; (or care of Messrs. Henry S. King and Co., 45 Pall Mall, London, S.W.)

1888. Davidson, Samuel Cleland, Sirocco Works, Bridge End, Belfast.

1884. Davies, Alfred Herbert, Eskell Chambers, Market Place, Nottingham.

1881. Davies, Benjamin, Bleach Works, Adlington, near Chorley.

1880. Davies, Charles Merson, Locomotive Carriage and Wagon Superintendent, Bengal-Nagpur Railway, Nagpur, Central Provinces, India.

1885. Davies, Edward John Mines, Gebrüder Sulzer, Winterthur, Switzerland.

1874. Davis, Alfred, Parliament Mansions, Westminster, S.W.

1868. Davis, Henry Wheeler, 53 New Broad Street, London, E.C.

1873. Davis, John Henry, Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester; and 90 Cannon Street, London, E.C.

1877. Davison, John Walter, care of W. G. P. Joyner, Pirie Chambers, Pirie Street, Adelaide, South Australia: (or care of Alfred L. Sacré, 60 Queen Victoria Street, London, E.C.)

1884. Davison, Robert, Caledonian Railway, Locomotive Department, St. Rollox, Glasgow.

1873. Davy, David, Messrs. Davy Brothers, Park Iron Works, Sheffield.

1883. Daw, James Gilbert, Messrs. Nevill Druce and Co., Llanelly Copper Works, Llanelly.

1874. Daw, Samuel, Staffa Lodge, South Park Hill Road, Croydon.

1879. Dawson, Bernard, 110 Cannon Street, London, E.C. [*Crocus, London.*]; and The Laurels, Malvern Link, Malvern. [*Heather, Malvern Link.*]

1869. Day, St. John Vincent, F.R.S.E., 115 St. Vincent Street, Glasgow; 122 George Street, Edinburgh [*Day Patents, Glasgow* and *Edinburgh.* 3021.] and Cawder House, Bishopbriggs, near Glasgow.

1886. Dayson, William Ogden, Ebbw Vale Steel Iron and Coal Works, Ebbw Vale, R.S.O., Monmouthshire.

1874. Deacon, George Frederick, Municipal Offices, Dale Street, Liverpool.

1880. Deacon, Richard William, 6 Lancaster Road, West Norwood, London, S.E.

1868. Dean, William, Locomotive Superintendent, Great Western Railway, Swindon.

1887. Deas, James, Clyde Navigation, Glasgow.

1866. Death, Ephraim, Messrs. Death and Ellwood, Albert Works, Leicester.

1884. Decauville, Paul, Portable Railway Works, Petit Bourg, Seine et Oise, France. [*Decauville, Corbeil.*]

1877. Dees, James Gibson, 36 King Street, Whitehaven.

1858. Dempsey, William, 26 Great George Street, Westminster, S.W.

1882. Denison, Samuel, Messrs. Samuel Denison and Son, Old Grammar School Foundry, North Street, Leeds. [*Weigh, Leeds.* 221.]

1883. Dennis, William Frederick, 101 Leadenhall Street, London, E.C. [*Fredennis, London.* 559.]

1888. Dent, Charles Hastings, Locomotive Department, London and North Western Railway, Crewe.

1880. De Pape, William Alfred Harry, Tottenham Board of Health, Coombes Croft House, High Road, Tottenham, Middlesex.

1883. Dick, Frank Wesley, Newton Steel Works, near Glasgow.

1882. Dick, Gavin Gemmell, 1 Westminster Chambers, 1 Victoria Street, Westminster, S.W.

1880. Dickinson, John, Palmer's Hill Engine Works, Sunderland. [*Bede, Sunderland.*]

1875. Dickinson, William, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.

1888. Dickson, George Manners, Assistant Engineer, Calcutta Water Works, Municipal Office, Calcutta, India.

1886. Dixon, Robert, Messrs. Dixon and Corbitt, Teams Hemp and Wire Rope Works, Gateshead. [*Dixon, Gateshead.*]

1883. Dixon, Samuel, Messrs. Kendall and Gent, Victoria Works, Springfield, Salford, Manchester. [*Tools, Manchester.*]

1887. Dixon, William Basil, Earle's Shipbuilding and Engineering Works, Hull.

1872. Dobson, Benjamin Alfred, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton. [*Dobsons, Bolton.*]

1873. Dobson, Richard Joseph Caistor, Suiker Fabriek, Kalibayor, Banjoemas, Java: (or care of Charles E. S. Dobson, 4 Chesterfield Buildings, Victoria Park, Clifton, Bristol.)

1880. Dodd, John, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1868. Dodman, Alfred, Highgate Foundry, Lynn. [*Dodman, Lynn.*]

1880. Donald, James, Messrs. Donald Henesey and Couper, Ripon Iron Works, Frere Road, Bombay; care of Messrs. John Fleming and Co., Bombay: (or care of Messrs. Fleming Wilson and Co., 24, 25, 27 Rood Lane, Fenchurch Street, London, E.C.)

1876. Donaldson, John, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W.; and Tower House, Turnham Green.

1873. Donkin, Bryan, Jun., Messrs. B. Donkin and Co., Southwark Park Road, Bermondsey, London, S.E.

1884. Donnelly, John, 45 Brockley Road, London, S.E.

1865. Douglas, Charles Prattman, Consett Iron Works, near Blackhill, County Durham; and Parliament Street, Consett, County Durham.

1879. Douglass, Sir James Nicholas, F.R.S., Trinity House, London, E.C. [2242.]; and Stella House, Dulwich, London, S.E.

1879. Douglass, William, Chief Engineer to the Commissioners of Irish Lights, Westmoreland Street, Dublin.

1887. Douglass, William Tregarthen, Executive Engineer, Bishop Rock and Round Island Lighthouses, Scilly Islands; and Trinity House, London, E.C.

1857. Dove, George, Messrs. Cowans Sheldon and Co., St. Nicholas Engine and Iron Works, Carlisle; and Viewfield, Stanwix, near Carlisle.

1873. Dove, George, Redbourn Hill Iron and Coal Co., Frodingham, near Doncaster [*Redbourn, Frodingham.*]; and Hatfield House, Hatfield, near Doncaster.

1866. Downey, Alfred C., Messrs. Downey and Co., Coatham Iron Works, Middlesbrough; and Post Office Chambers, Middlesbrough.

1881. Dowson, Joseph Emerson, 3 Great Queen Street, Westminster, S.W. [*Gaseous, London.*]

1886. Doxford, Charles David, Messrs. William Doxford and Sons, Pallion Shipbuilding and Engine Works, Sunderland.

1880. Doxford, Robert Pile, Messrs. William Doxford and Sons, Pallion Shipbuilding and Engine Works, Sunderland.

1874. Dredge, James, 35 Bedford Street, Strand, London, W.C. [3663.]

1886. Drummond, Dugald, Locomotive Superintendent, Caledonian Railway, St. Rollox Works, Glasgow.

1877. Dübs, Charles Ralph, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1877. Dübs, Henry John Sillars, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1885. Duckering, Charles, Water Side Works, Rosemary Lane, Lincoln.

1880. Duckham, Frederic Eliot, Engineer, Millwall Docks, London, E.

1881. Duckham, Heber, 184 Lewisham Road, London, S.E. [*Duckham, London.*]

1879. Duncan, David John Russell, Messrs. Duncan Brothers, 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W. [*Doucine, London.*]; and 10 Airlie Gardens, Campden Hill, Kensington, London, W.

1886. Duncan, Norman, Mechanical Engineer to the Municipality, Rangoon, British Burmah, India.

1870. Dunlop, James Wilkie, 39 Delancey Street, Regent's Park, London, N.W.

1881. Dunn, Henry Woodham, Knysna, Cape Colony; and Livonia, Goldsmith Gardens, Acton, London, W.

1885. Durham, Frederick William, 27 Leadenhall Street, London, E.C. [*Oilring, London.*]; and Glemham Lodge, New Barnet.

1887. Dymond, George Cecil, Messrs. W. P. Thompson and Co., 6 Lord Street, Liverpool.

1865. Dyson, Robert, Messrs. Owen and Dyson, Rother Iron Works, Rotherham.

1880. Eager, John Edward, Messrs. William Crichton and Co., Engineering and Shipbuilding Works, Abo, Finland.

1869. Earnshaw, William Lawrence, Superintending Marine Engineer, South Eastern Railway, Folkestone.

1858. Easton, Edward, 11 Delahay Street, Westminster, S.W.

1884. Eastwood, Charles, Manager, Linacre Gas Works, Liverpool.

1888. Eaton-Shore, George, Borough Engineer, Temple Chambers, Crewe.

1875. Eaves, William, Engineer, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield.

1878. Eckart, William Roberts, Messrs. Salkeld and Eckart, 632 Market Street, P. O. Box 1844, San Francisco, California, United States.

1868. Eddison, Robert William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1886. Ede, Francis Joseph, Messrs. Ede Brothers, Silchar, Cachar, India.

1887. Edlin, Herbert William, The Limes, Ellerton Road, Surbiton, R. O., Kingston-on-Thames.

1883. Edmiston, James Brown, Marine Superintending Engineer, Messrs. Hamilton Fraser and Co., K Exchange Buildings, Liverpool; and Ivy Cottage, Highfield Road, Walton, Liverpool.

1871. Edwards, Edgar James, 42 Rye Hill Park, Peckham, London, S.E.

1877. Edwards, Frederick, 62 Bishopsgate Street Within, London, E.C.

1866. Elce, John, Eton House, Buxton, Derbyshire.

1879. Ellacott, Robert Henry, Messrs. Ellacott and Co., Plymouth Foundry, Plymouth. [*Ellacott, Plymouth.* 47.]

1888. Ellery, Henry George, Messrs. Gent and Co., Faraday Works, Leicester.

1875. Ellington, Edward Bayzand, Hydraulic Engineering Works, Chester; and Hydraulic Engineering Co., Palace Chambers, 9 Bridge Street, Westminster, S.W.

1859. Elliot, Sir George, Bart., M.P., Houghton-le-Spring, near Fence Houses.

1883. Elliott, Henry John, Assistant Manager, Elliott's Metal Works, Selly Oak, near Birmingham. [*Elmeco, Birmingham.*]

1869. Elliott, Henry Worton, Selly Oak Works, near Birmingham. [*Elmeco, Birmingham.*]

1882. Elliott, Thomas Graham, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1880. Ellis, Oswald William, 6 Grosvenor Place, Jesmond, Newcastle-on-Tyne. [*Robey, Newcastle-on-Tyne.*]

1885. Elsworthy, Edward Houtson, Messrs. Richardson and Cruddas, Byculla Iron Works, Bombay, India.

1869. Elwell, Alfred, Edge Tool Works, Wood Green, Wednesbury.

1875. Elwell, Thomas, 223 Avenue de Paris, Plaine St. Denis, Seine, France.

1878. Elwin, Charles, Metropolitan Board of Works, Spring Gardens, London, S.W.

1885. Errington, William, 28 and 29 Insurance Buildings, Auckland, New Zealand. [*Refunditur, Auckland.*]

1884. Etherington, John, 39A King William Street, London Bridge, London, E.C.

1887. Evans, Arthur George, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1884. Evans, David, Barrow Hæmatite Steel Works, Barrow-in-Furness.

1888. Evans, Joseph, Culwell Foundry, Wolverhampton.

1885. Evans, Richard Kendall, Engineering Works, Sandiacre, near Nottingham.

1887. Everard, John Breedon, 6 Millstone Lane, Leicester.

1887. Everitt, Nevill Henry, Patent Shaft Works, Wednesbury.

1864. Everitt, William Edward, Messrs. Allen Everitt and Sons, Kingston Metal Works, Adderley Street, Birmingham; and Finstal, Bromsgrove.

1881. Ewen, Thomas Buttwell, Smithfield Works, Sherlock Street, Birmingham.

1869. Faija, Henry, 2 Great Queen Street, Westminster, S.W.

1868. Fairbairn, Sir Andrew, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds; and Askham Richard, York.

1875. Farcot, Jean Joseph Léon, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1880. Farcot, Paul, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1867. Fardon, Thomas, 106 Queen Victoria Street, London, E.C.; and 63 Collingdon Street, Luton.

1881. Farrar, Sidney Howard, Messrs. Howard Farrar and Co., Port Elizabeth, South Africa; and 69 Cornhill, London, E.C.

1882. Fawcett, Thomas Constantine, White House Engineering Works, Leeds. [*Fawcett, Leeds.*]

1884. Fearfield, John Piggin, Lace Machine Works, Stapleford, near Nottingham; and The Ferns, Stapleford, near Nottingham. [*Fearfield, Nottingham.*]

1888. Featherstone, William Bromley, Engineer and Manager, Dundalk Gas Works, Dundalk.

1882. Feeny, Victor Isidore, 7 Queen Victoria Street, London, E.C.

1876. Fell, John Corry, 1 Queen Victoria Street, London, E.C.; and Excelsior Works, Old Street, London, E.C.

1877. Fenton, James, 8 Great George Street, Westminster, S.W.

1869. Fenwick, Clennell, Victoria Docks Engine Works, Victoria Docks, London, E. [*Clennell, London.*]

1870. Ferguson, Henry Tanner, Plumley, Bovey Tracey, near Newton Abbot.

1881. Ferguson, William, Harbour Board, Wellington, New Zealand: (or care of Montgomery Ferguson, 81 James Street, Dublin.)

1854. Fernie, John, P. O. Box, Hutchinson, Kansas, United States.

1866. Fiddes, Walter, Engineer, Bristol United Gas Works, Bristol.

1867. Field, Edward, Chandos Chambers, 22 Buckingham Street, Adelphi, London, W.C.

1888. Field, Howard, Messrs. John Bell and Son, 118A Southwark Street, London, S.E.; and Southall.

1884. Fielden, Joseph Petrie, Messrs. Thomas Robinson and Son, Railway Works, Rochdale.

1874. Fielding, John, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester. [*Atlas, Gloucester.*]

1887. Firth, William, Water Lane, Leeds.

1888. Fischer, Gustave Joseph, Resident Engineer, Railway Department, Sydney, New South Wales.

1884. Fisher, Henry Oakden, Engineer, Taff Vale Railway, Cardiff.

1885. Fitton, Joseph, Derwent Street, Ordsal Lane, Salford, Manchester.

1888. FitzGerald, Maurice Frederick, Professor of Engineering, Queen's College, Belfast.

1877. Flannery, James Fortescue, 9 Fenchurch Street, London, E.C. [2283.]

1864. Fleet, Thomas, Mayfield, Beeches Road, Westbromwich.

1847. Fletcher, Edward, 2 Osborne Avenue, West Jesmond, Newcastle-on-Tyne.

1883. Fletcher, George, Masson and Atlas Works, Litchurch, Derby.

1872. Fletcher, Herbert, Ladyshore Colliery, Little Lever, Bolton; and The Hollins, Bolton.

1867. Fletcher, Lavington Evans, Chief Engineer, Manchester Steam Users' Association, 9 Mount Street, Albert Square, Manchester. [*Steam Users, Manchester.*]

1872. Flower, James J. A., Messrs. James Flower and Sons, St. Mary's Chambers, St. Mary Axe, London, E.C. [*Floramour, London.* 551.]

1859. Fogg, Robert, 11 Queen Anne's Gate, Westminster, S.W.

1887. Foley, Nelson, Engineering Manager, Società Industriale Napoletana Hawthorn-Guppy, Naples, Italy.

1886. Folger, William Mayhew, Commander, United States Navy, Bureau of Ordnance, Naval Department, Washington, D.C., United States.

1877. Forbes, Daniel Walker, Smithfield Works, New Road, Blackwall, London, E.

1882. Forbes, David Moncur, Engineer, H. M. Mint, Calcutta.

1882. Forbes, William George Loudon Stuart, Superintendent of General Workshops, H. M. Mint, Calcutta.

1888. Forster, Alfred Llewellyn, Assistant Engineer, Newcastle and Gateshead Water Works, Newcastle-on-Tyne.

1888. Forster, Edward John, Messrs. Chance Brothers and Co., Lighthouse Works, near Birmingham.

1882. Forsyth, Robert Alexander, Austin Villa, Chepstow Road, Newport, Monmouthshire.

1886. Foster, Frederick, Messrs. Barnett and Foster, Niagara Works, Eagle Wharf Road, New North Road, London, N. [*Drinks, London.* 306.]

1888. Foster, James, Samarang, Java; and 8 The Grove, Sunderland. [*Java, Sunderland.*]

1884. Foster, John Slater, Messrs. Jones and Foster, 39 Bloomsbury Street, Birmingham.

1882. Fothergill, John Reed, Superintendent Marine Engineer, 1 Bathgate Terrace, West Hartlepool.

1877. Foulis, William, Engineer, Glasgow Corporation Gas Works, 42 Virginia Street, Glasgow.

1885. Fourny, Hector Foster, Earle's Shipbuilding and Engineering Works, Hull.

1866. Fowler, George, Basford Hall, near Nottingham.

1847. Fowler, Sir John, K.C.M.G., 2 Queen Square Place, Westminster, S.W.

1885. Fowler, William Henry, Rose Villas, St. Mary's Road, Newton Heath, near Manchester.

1866. Fox, Sir Douglas, 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W.

1875. Fox, Samson, Leeds Forge, Leeds.

1882. Fox, William, Leeds Forge, Leeds.

1884. Frampton, Edwin, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E. [*Oxygen, London.* 8007.]

1888. Francken, William Augustus, Public Works Department, India; care of Messrs. Grindlay and Co., 55 Parliament Street, Westminster, S.W.

1885. Franki, James Peter, Morts Dock and Engineering Co., Morts Bay, Sydney, New South Wales: (or care of Messrs. Mort and Co., 155 Fenchurch Street, London, E.C.)

1877. Fraser, John Hazell, Messrs. Fraser Brothers, Railway Iron Works, Bromley, London, E. [*Pressure, London.* 5420.]

1888. Frenzel, Arthur Benjamin, 49 Queen Victoria Street, London, E.C.

1876. Frost, William, Manager, Carlisle Steel and Engine Works, Sheffield; and Woodhill, Sheffield.

1866. Fry, Albert, Bristol Wagon Works, Lawrence Hill, Bristol.

1886. Fulton, Arthur Robert William, Resident Engineer, Wellington and Manawatu Railway, Wellington, New Zealand.

1884. Furness, Edward, Knollcroft, Knoll Road, Bexley, S.O., Kent.

1882. Furrell, Edward Wyburd, Bank of Commerce Building, St. Louis, Missouri, United States.

1887. Gaertner, Ernst, Messrs. Klein Brothers Schmoll and Gaertner, III Jaquingasse 13, Vienna, Austria.

1866. Galloway, Charles John, Messrs. W. and J. Galloway and Sons, Knott Mill Iron Works, Manchester. [*Galloway, Manchester.*]

1862. Galton, Sir Douglas, K.C.B., D.C.L., F.R.S., 12 Chester Street, Grosvenor Place, London, S.W.

1884. Ganga Ram, Lala, Executive Engineer, Public Works Department, Amritsar, Punjaub, India.

1882. Garrett, Frank, Messrs. Richard Garrett and Sons, Leiston Works, Leiston R.S.O., Suffolk. [*Garrett, Leiston.*]

1867. Gauntlett, William Henry, 33 Albert Terrace, Middlesbrough. [*Pyrometer, Middlesbrough.*]

1888. Gaze, Edward Henry James, 4 Victoria Drive, Mount Florida, Glasgow.

1888. Geddes, Christopher, Leeds Forge Co., Leeds.

1880. Geoghegan, Samuel, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin. [*Guinness, Dublin.*]

1887. Gibb, Andrew, Managing Engineer, Messrs. Rait and Gardiner, Millwall Docks, London, E.

1871. Gibbins, Richard Cadbury, Berkley Street, Birmingham. [*Gibbins, Birmingham.*]

1872. Gilbert, Ebenezer Edwin, Canada Engine Works, Montreal, Canada.

1883. Gilchrist, Percy Carlyle, Palace Chambers, 9 Bridge Street, Westminster, S.W. [*Gilchrist, London.*]

1856. Gilkes, Edgar, Messrs. Thompson and Gilkes, Stockton-on-Tees; and Ingleside, Stockton-on-Tees.

1880. Gill, Charles, Messrs. Young and Gill, Engineering Works, Java; and Java Lodge, Beckenham.

1866. Gilroy, George, Engineer, Ince Hall Colliery, Wigan.
1884. Gimson, Arthur James, Messrs. Gimson and Co., Engine Works, Vulcan Street, Leicester. [*Gimson, Leicester.* 6.]
1884. Girdlestone, John Ward, Engineer, Bristol Docks, Bristol.
1881. Girdwood, William Wallace, Indestructible Packing Works, 9 Lea Place, East India Dock Road, Poplar, London, E.
1874. Gjers, John, Messrs. Gjers Mills and Co., Ayresome Iron Works, Middlesbrough.
1887. Gledhill, Manassah, Sir Joseph Whitworth and Co., Openshaw, Manchester.
1880. Godfrey, William Bernard, 23 St. Swithin's Lane, London, E.C.
1888. Goff, John, Messrs. Salt and Co., The Brewery, Burton-on-Trent.
1882. Goldsmith, Alfred Joseph, Messrs. John Walker and Co., Union Foundry and Shipbuilding Works, Maryborough, Queensland: (or care of Messrs. James McEwan and Co., 27 Lombard Street, London, E.C.)
1879. Goldsworthy, Robert Bruce, Messrs. Thomas Goldsworthy and Sons, Britannia Emery Mills, Hulme, Manchester. [*Goldsworthy, Manchester.*]
1867. Gooch, William Frederick, Vulcan Foundry, Newton-le-Willows, Lancashire.
1884. Good, Henry, Messrs. Jardine and Co., Shanghai, China: care of Marine Engineers' Institute, Shanghai, China.
1877. Goodbody, Robert, Messrs. Goodbody, Clashawaun Jute Factory, Clara, near Moate, Ireland.
1869. Goodeve, Thomas Minchin, 5 Crown Office Row, Temple, London, E.C.
1875. Goodfellow, George Ben, Messrs. Goodfellow and Matthews, Hyde Iron Works, Hyde, near Manchester. [*Goodfellow, Hyde.*]
1884. Goodger, Walter William, Messrs. George Fletcher and Co., Masson and Atlas Works, Litchurch, Derby.
1885. Goodwin, Arnold, Jun., 56 Sumner Street, Southwark, London, S.E.
1865. Göransson, Göran Fredrick, Sandvik Iron Works, near Gefle, Sweden: (or care of James Bird, 118 Cannon Street, London, E.C.)
1887. Gordon, Alexander, Niles Tool Works, and Messrs. Gordon and Maxwell, Hamilton, Ohio, United States.
1875. Gordon, Robert, Fernhill, Henbury, near Bristol: (or care of Messrs. Henry S. King and Co., 45 Pall Mall, London, S.W.)
1888. Gore, Arthur Saunders, Locomotive Superintendent, Listowel and Ballybunion Railway, Listowel, County Kerry, Ireland.
1879. Gorman, William Augustus, Messrs. Siebe and Gorman, 187 Westminster Bridge Road, London, S.E. [*Siebe, London.*]
1880. Gottschalk, Alexandre, 13 Rue Auber, Paris.
1877. Goulty, Wallis Rivers, Messrs. Wheatley Kirk, Price, and Goulty, Albert Chambers, Albert Square, Manchester. [*Indicator, Manchester.*]
1887. Gourlay, Charles Gershom, Messrs. Gourlay Brothers and Co., Dundee Foundry, Dundee.

1878. Grafton, Alexander, Bedford.

1865. Gray, John Macfarlane, Chief Examiner of Engineers, Marine Department, Board of Trade, St. Katharine Dock House, Tower Hill, London, E.; and 1 Claremont Road, Forest Gate, London, E.

1876. Gray, John William, Engineer, Corporation Water Works, Broad Street, Birmingham.

1879. Gray, Thomas Lowe, Lloyd's Register, 2 White Lion Court, Cornhill, London, E.C.; and Rokesley House, St. Michael's Road, Stockwell, London, S.W.

1879. Greathead, James Henry, 8 Victoria Chambers, Victoria Street, Westminster, S.W.

1861. Green, Sir Edward, Bart., M.P., Messrs. E. Green and Son, Phœnix Works, Wakefield.

1888. Green, Henry Joseph Kersting, Engineer, Bishnauth Tea Co., Charalli Post Office, Assam, Bengal.

1871. Greener, John Henry, 15 Walbrook, London, E.C.

1878. Greenwood, Arthur, Messrs. Greenwood and Batley, Albion Works, Leeds.

1874. Greenwood, William Henry, Professor of Metallurgy and Mechanical Engineering, Firth College, Sheffield.

1865. Greig, David, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds. [*Greig, Fowler, Leeds.* 155.]

1885. Greig, David, Jun., Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1879. Grenville, Robert Neville, Butleigh Court, Glastonbury.

1880. Gresham, James, Messrs. Gresham and Craven, Craven Iron Works, Ordsal Lane, Salford, Manchester. [*Brake, Manchester.*]

1883. Grew, Frederick, Whitmore Place, 418 Coventry Road, Small Heath, Birmingham.

1874. Grew, Nathaniel, Dashwood House, 9 New Broad Street, London, E.C.

1866. Grice, Edwin James, Beechwood, Reigate.

1884. Griffiths, James E., Messrs. Griffiths and Wills, Merchants' Exchange, Cardiff. [*Griffwill, Cardiff.*]

1873. Griffiths, John Alfred, Sherwood, near Brisbane, Queensland.

1879. Grose, Arthur, Manager, Vulcan Iron Works, Guildhall Road, Northampton.

1886. Grove, David, 24 Friedrich Strasse, Berlin.

1870. Guilford, Francis Leaver, Messrs. G. R. Cowen and Co., Beck Works, Brook Street, Nottingham. [*Cowen, Nottingham.* 87.]

1883. Guinotte, Lucien, Mariemont and Bascoup Collieries, Mariemont, Belgium.

1884. Gulland, James Ker, Diamond Drill Co., 8 Victoria Street, Westminster, S.W. [*Gulland, London.*]

1886. Guy, Charles Williams, Laurel Bank, Penge, London, S.E.

1870. Gwynne, James Eglinton Anderson (*Life Member*), Essex Street Works, Strand, London, W.C. [*Gwynnegram, London.*]

1870. Gwynne, John, Hammersmith Iron Works, Hammersmith, London, W.

1879. Hadfield, Robert, Hadfield Steel Foundry Co., Attercliffe, Sheffield. [*Hadfield, Sheffield.*]

1888. Hadfield, Robert Abbott, Hecla Foundry Steel Works, Sheffield.

1884. Hall, Albert Francis, George F. Blake Manufacturing Co., 111 Federal Street, Boston; and 3 Cordis Street, Charlestown, Boston, Massachusetts, United States.

1879. Hall, John Francis, Messrs. W. Jessop and Sons, Brightside Steel Works, Sheffield.

1881. Hall, John Percy, Engine Works Department, Messrs. Palmer's Shipbuilding and Iron Works, Jarrow.

1882. Hall, John Willim, Ivy House, Bilston.

1874. Hall, Thomas Bernard, Patent Nut and Bolt Works, Smethwick, near Birmingham; and Ingleside, Sandon Road, Edgbaston, Birmingham.

1886. Hall, William Jeremiah, Harbour Engineer, Limerick, Ireland.

1871. Hall, William Silver, 86 Newman Street, Oxford Street, London, W.; and 39 Hartington Street, Derby. [*Silver Hall, Derby.*]

1880. Hallett, John Harry, 120 Powell's Place, Bute Docks, Cardiff. [*Consulting, Cardiff.*]

1871. Halpin, Druitt, 9 Victoria Chambers, 17 Victoria Street, Westminster, S.W. [*Halpin, London.* 3075, care of Victoria Chambers Co.]

1888. Hamilton, Alfred George, 14 Griffin Street, York Road, London, S.E.

1875. Hammond, Walter John, Resident Engineer and Locomotive Superintendent, Paulista Railway, Jundiahy, São Paulo, Brazil; (or care of Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.)

1886. Hanbury, John James, Resident Engineer and Locomotive Superintendent, Metropolitan Railway, Neasden, London, N.W.

1870. Hannah, Joseph Edward, Water Works, Winnipeg, Manitoba, Canada.

1888. Harada, Torazo, Superintending Engineer, Osaka Shipping Co., Osaka, Japan.

1888. Harding, Thomas Walter, Tower Works, Leeds.

1874. Harding, William Bishop, Zerge-utcza 13, Budapest, Hungary.

1881. Hardingham, George Gatton Melhuish, 191 Fleet Street, London, E.C. [*Hardingham, London.*]

1883. Hardy, John George, 13 Riemergasse, Stadt, Vienna.

1869. Harfield, William Horatio, Mansion House Buildings, Queen Victoria Street, London, E.C.

1887. Hargraves, Richard, Messrs. B. Donkin and Co., Southwark Park Road, Bermondsey, London, S.E.

1887. Hargreaves, John Henry, Messrs. Hick Hargreaves and Co., Soho Iron Works, Crook Street, Bolton.

1884. Harker, Harold Hayes, Locomotive Superintendent, Minas and Rio Railway, Cruzeiro, Rio de Janeiro, Brazil: (or care of Jesse T. Curtis, Hill Street, Poole.)

1888. Harker, William, Messrs. Richard Schram and Co., 17A Great George Street, Westminster, S.W.

1888. Harland, Sir Edward James, Bart., Messrs. Harland and Wolff, Belfast; and Glenarm Castle, County Antrim.

1873. Harman, Harry Jones, 36 Gaisford Street, Kentish Town, London, N.W.

1879. Harris, Henry Graham, 5 Great George Street, Westminster, S.W.

1885. Harris, John Henry, Worthington Pumping Engine Co., 153 Queen Victoria Street, London, E.C. [*Tuneharp, London.*]

1873. Harris, Richard Henry, 63 Queen Victoria Street, London, E.C.; and Oak Hill, Surbiton, R.O., near Kingston-on-Thames.

1877. Harris, William Wallington, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.; and 24 Alexandra Villas, Hornsey Park, London, N.

1885. Harrison, Frederick Henry, Lincoln Malleable Iron Works, Lincoln. [*Malleable, Lincoln.*]

1888. Harrison, George, 13 West View, Hill Street, Withington, near Manchester.

1885. Harrison, Joseph, Normal School of Science, South Kensington, London, S.W.

1858. Harrison, Thomas Elliot, Engineer-in-Chief, North Eastern Railway, Newcastle-on-Tyne.

1887. Harrison, Thomas Henry, Messrs. Davey Paxman and Co., 139 Queen Victoria Street, London, E.C.; and 22 Granville Villas, Earlsfield Road, Wandsworth, London, S.W.

1883. Hart, Frederick, 36 Prospect Street, Poughkeepsie, New York, United States: (or care of A. Pye-Smith, Messrs. Samuel Osborn and Co., 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W.)

1882. Hart, Norman, London Chatham and Dover Railway, Locomotive (Marine) Department, Dover.

1872. Hartnell, Wilson, Benson's Buildings, Park Row, Leeds.

1882. Harvey, Charles Randolph, Messrs. G. and A. Harvey, Albion Machine Works, Govan, near Glasgow.

1886. Harvey, John Boyd, The Liverpool Nitrate Co., Oficina Ramirez, Iquique, Chile: (or care of Robert Harvey, 12 Kensington Gore, London, S.W.)

1883. Harvey, Robert, 12 Kensington Gore, London, S.W.

1878. Harwood, Robert, Soho Iron Works, Bolton.

1882. Haskins, John Ferguson, 114A Queen Victoria Street, London, E.C. [*Haskins, London.* 1539.]; and Fallulah, York Road, West Norwood, London, S.E.

1881. Haslam, Alfred Seale, Union Foundry, Derby. [*Zero, Derby.*]

1858. Haswell, John A., North Eastern Railway, Locomotive Department, Gateshead.

1885. Hatton, Robert James, Henley's Telegraph Works, North Woolwich, London, E.

1888. Hattori, Shiun-ichi, Owari Cotton Mill, Atsuta, Owari, Japan.

1857. Haughton, S. Wilfred (*Life Member*), Greenbank, Carlow, Ireland.

1878. Haughton, Thomas, 110 Cannon Street, London, E.C. [*Haughnot, London.*]

1885. Haughton, Thomas James, Belmont, 70 West Hill, Sydenham, London, S.E.

1861. Hawkins, William Bailey, 39 Lombard Street, London, E.C.

1870. Hawksley, Charles, 30 Great George Street, Westminster, S.W.

1856. Hawksley, Thomas, F.R.S., 30 Great George Street, Westminster, S.W.

1873. Hay, James A. C., Superintendent of Machinery to the War Department, Royal Arsenal, Woolwich.

1882. Hayes, Edward, Watling Works, Stony Stratford. [*Hayes, Stony Stratford.*]

1879. Hayes, John, Messrs. Gwynne and Co., Essex Street Works, Strand, London, W.C.; and 28 Connaught Road, Harlesden, London, N.W.

1880. Hayter, Harrison, 33 Great George Street, Westminster, S.W.

1888. Head, Harold Ellershaw, Messrs. Conway Brothers, Pontrhydyrun Works, near Newport, Monmouthshire.

1869. Head, Jeremiah, Messrs. Fox Head and Co., Newport Rolling Mills, Middlesbrough, [*Head, Foxhead, Middlesbrough.* 22.]; and 26 Lombard Street, London, E.C.

1873. Headly, Lawrance, Exchange Iron Foundry and Implement Works, Corn Exchange Street, Cambridge; and 1 Camden Place, Cambridge. [*Vanes, Cambridge.*]

1857. Healey, Edward Charles, 163 Strand, London, W.C.

1872. Heap, William, 9 Rumford Place, Liverpool. [*Metal, Liverpool.* 809.]

1864. Heathfield, Richard, Lion Galvanising Works, Darlaston, R.O., near Wednesbury.

1888. Heatly, Harry, Craven Iron Works, Ordsal Lane, Salford, Manchester.

1875. Heenan, Richard Hammersley, Messrs. Heenan and Froude, Newton Heath Iron Works, near Manchester. [*Spherical, Newton Heath.*]

1879. Henchman, Humphrey, English Scottish and Australian Chartered Bank, Sydney, New South Wales: (or care of John Henchman, Uplands, Wallington, Surrey.)

1869. Henderson, David Marr, Engineer-in-Chief, Imperial Maritime Customs Service of China, Shanghai, China.

1883. Henderson, John Baillie, Engineer to the Queensland Government, Water Supply Department, Brisbane, Queensland.

1883. Henderson, William, El Callao Mine, Cuidad, Bolivar, Venezuela, South America: (or care of Mrs. Henderson, 7 Rutland Street, Pimlico, London, S.W.)

1878. Henesey, Richard, Messrs. Donald Henesey and Couper, Ripon Iron Works, Frere Road, Bombay; and 3 Beckett Terrace, Uxbridge.

1888. Henning, Gustavus Charles, 18 Cedar Street, New York, United States; and 30 Kirby Street, Hatton Garden, London, E.C.

1879. Henriques, Cecil Quixam, 113 Cannon Street, London, E.C.

1875. Hepburn, George, Redcross Chambers, Redcross Street, Liverpool. [*Hepburn, Liverpool.*]

1876. Heppell, Thomas, Mining Engineer, Ouston Collieries, Chester-le-Street.

1884. Hernu, Arthur Henry, 69 Victoria Street, Westminster, S.W.

1884. Hervey, Matthew Wilson, Assistant Engineer, West Middlesex Water Works, Hammersmith, London, W.

1879. Hesketh, Everard, Messrs. J. and E. Hall, Iron Works, Dartford. [*Hesketh, Dartford.*]

1872. Hewlett, Alfred, Haseley Manor, Warwick.

1887. Hibbert, George, Hibbert's Works, Bank Road, Gateshead-on-Tyne.

1871. Hick, John, Mytton Hall, Whalley, near Blackburn.

1885. Hicken, Thomas, Remeco, Traiguen, Chili: (or care of John Hicken, Bourton, near Rugby.)

1864. Hide, Thomas C., 4 Cullum Street, Fenchurch Street, London, E.C.

1879. Higson, Jacob, Mining Engineer, Crown Buildings, 18 Booth Street, Manchester.

1871. Hill, Alfred C., Clay Lane Iron Works, South Bank, R.S.O., Yorkshire.

1885. Hill, Robert Anderson, Royal Mint, Little Tower Hill, London, E.

1882. Hiller, Henry, Chief Engineer, National Boiler Insurance Company, 22 St. Ann's Square, Manchester.

1873. Hilton, Franklin, Chief Engineer, Messrs. Bolckow Vaughan and Co., Iron Works, Middlesbrough: and South Bank, R.S.O., Yorkshire.

1876. Hind, Thomas William, Messrs. Henry Hind and Son, Central Engineering Tool Works, Queen's Road, Nottingham [*Hind, Nottingham.*]; and 62 Blackfriars Road, London, S.E.

1885. Hindmarsh, Thomas, 303 King Street West, Hammersmith, London, W.

1887. Hindson, William, Messrs. J. Abbot and Co., Park Works, Gateshead.

1870. Hodges, Petronius, 238 Barnsley Road, Sheffield.

1880. Hodgson, Charles, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W.

1882. Hodson, Richard, Thames Iron Works and Shipbuilding Co., Blackwall, London, E.

1884. Hogg, William Thomas, Ram Brewery, Wandsworth, London, S.W.

1866. Holcroft, Thomas, Bilston Foundry, Bilston.

1886. Holden, James, Locomotive Superintendent, Great Eastern Railway, Stratford Works, London, E.

1884. Holland, Calvert Bernard, General Manager, Ebbw Vale Steel Iron and Coal Works, Ebbw Vale, R.S.O., Monmouthshire.

1886. Hollis, Charles William, Messrs. Ketton and Hollis, Meadow Tool Works, Mayfield Grove, Nottingham.

1885. Hollis, Henry William, North Lodge, Darlington.

1883. Holroyd, John, Tomlinson Street, Hulme, Manchester. [*Knit, Manchester.*]

1885. Holroyd, John Herbert, West's Patent Press Company, Etawah, N.W. Provinces, India.

1863. Holt, Francis, Midland Railway, Locomotive Department, Derby.

1873. Holt, Henry Percy, The Cedars, Didsbury, Manchester.

1867. Holt, William Lyster, 17 Parliament Street, Westminster, S.W.

1888. Homan, Harold, Messrs. Homan and Rodgers, Dawson Street, Manchester.

1867. Homer, Charles James, Mining Engineer, Ivy House, Stoke-upon-Trent.

1883. Hooton, William, Continental Lace-Machine Works, Great Eastern Street, Nottingham.

1866. Hopkins, John Satchell, Jesmond Grove, Highfield Road, Edgbaston, Birmingham.

1885. Hopkinson, Charles, Werneth Chambers, 29 Princess Street, Manchester.

1856. Hopkinson, John, Inglewood, St. Margaret's Road, Bowdon, near Altrincham.

1874. Hopkinson, John, Jun., D.Sc., F.R.S., Messrs. Chance Brothers and Co., Lighthouse Works, near Birmingham; and 3 Westminster Chambers, 5 Victoria Street, Westminster, S.W. [3092.]

1877. Hopkinson, Joseph, Messrs. Joseph Hopkinson and Co., Britannia Works, Huddersfield.

1880. Hornsby, James, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham. [*Hornsbys, Grantham.*]

1873. Horsley, Charles, 22 Wharf Road, City Road, London, N.

1858. Horsley, William, Whitehill Point Iron Works, Percy Main, near Newcastle-on-Tyne.

1868. Horton, Enoch, Alma Works, Darlaston, near Wednesbury.

1871. Horton, George, 4 Cedars Road, Clapham Common, London, S.W.

1875. Hosgood, Thomas Hopkin, Richardson Street, Swansea.

1873. Hoskin, Richard, 1 East Parade, Sheffield.

1888. Hosking, Thomas, Messrs. T. and J. Hosking, Dockhead Iron Works, 53 Parker's Row, Bermondsey, London, S.E.

1866. Houghton, John Campbell Arthur, Woodside Iron Works, near Dudley.

1887. Houghton-Brown, Ernest, Messrs. Houghton-Brown Brothers, Kingsbury Iron Works, Ballspond, London, N.

1864. Howard, Eliot, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1860. Howard, James, Messrs. J. and F. Howard, Britannia Iron Works, Bedford; and Clapham Park, Bedfordshire. [*Howard, Bedford.*]

1882. Howard, John William, 78 Queen Victoria Street, London, E.C.

1885. Howarth, William, Manager, Oldham Boiler Works, Oldham. [*Boilers, Oldham.*]

1861. Howell, Joseph Bennett, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield. [*Howell, Sheffield.*]

1877. Howell, Samuel Earnshaw, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield. [*Howell, Sheffield.*]

1882. Howl, Edmund, Messrs. Lee Howl and Co, Tipton. [*Howl, Tipton.*]

1877. Howlett, Francis, Messrs. Henry Clayton Son and Howlett, Atlas Works, Woodfield Road, Harrow Road, London, W. [*Brickpress, London.*]

1884. Hoyle, Frank Edward, Locomotive Superintendent, Bahia and San Francisco Railway, Periperi, Bahia, Brazil: (or care of Leonard Micklem, Secretary, Bahia and San Francisco Railway, 38 New Broad Street, London, E.C.)

1887. Hoyle, James Rossiter, Messrs. Thomas Firth and Sons, Norfolk Works, Sheffield.

1882. Hudson, John George, 18 Aytoun Road, Pollokshields, Glasgow.

1884. Hudson, Robert, Gildersome Foundry, near Leeds [*Gildersome, Leeds.* 14.]; and Weetwood Mount, Headingley, near Leeds. [454.]

1881. Hughes, Edward William Mackenzie, Locomotive and Carriage Superintendent, North-Western State Railway, Sukkur, Sindh Section, India; and Balfunning, Sutherland Crescent, Helensburgh.

1867. Hughes, George Douglas, Queen's Foundry, London Road, Nottingham.

1871. Hughes, Joseph, Kingston, Wareham.

1864. Hulse, William Wilson, Ordsal Tool Works, Regent Bridge, Salford, Manchester.

1880. Humphrys, James, 16 and 17 Leadenhall Buildings, London, E.C.; and Arundel House, Lancaster Road, South Norwood Park, London, S.E.

1866. Humphrys, Robert Harry, Messrs. Humphrys Tennant and Co., Deptford Pier, London, S.E.

1882. Hunt, Reuben, Aire and Calder Chemical Works, Castleford, near Normanton.

1885. Hunt, Richard, Messrs. Thomas Hunt and Sons, Albion Iron Works, 132 Bridge Road West, Battersea, London, S.W.

1856. Hunt, Thomas, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1874. Hunt, William, Alkali Works, Lea Brook, Wednesbury; Hampton House, Wednesbury; and Aire and Calder Chemical Works, Castleford, near Normanton.

1886. Hunter, John, Messrs. Campbells and Hunter, Dolphin Foundry, Saynor Road, Hunslet, Leeds.

1877. Hunter, Walter, Messrs. Hunter and English, High Street, Bow, London, E. [*Venator, London.*]

1888. Huxley, George, 20 Mount Street, Manchester.

1885. Hyland, John Frank, Engineer to Navigation of Paulista Railway, Campinas, São Paulo, Brazil: (or care of Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.)

1877. Imray, John, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C.

1882. Ingham, William, 22 St. Ann's Square, Manchester.

1888. Ingleby, Joseph, 20 Mount Street, Manchester.

1872. Inman, Charles Arthur, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead; and 45 North Corridor, The Albany, Liverpool.

1883. Instone, Thomas, 22 Leadenhall Buildings, Leadenhall Street, London, E.C.

1887. Ivatt, Henry Alfred, Locomotive Engineer, Great Southern and Western Railway, Inchicore Works, near Dublin.

1887. Ivatts, Lionel Edward, 50 Avenue de la Grande Armée, Paris.

1884. Jacks, Thomas William Moseley, Patent Shaft Works, Wednesbury; and 72 Stafford Street, Wednesbury.

1859. Jackson, Matthew Murray, 47 Norton Road, West Brighton, Brighton; and care of Messrs. Howard and Pitcairn, 155 Fenchurch Street, London, E.C.

1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester; and Blackbrooke, Pontrilas, R.S.O., Herefordshire. [*Jacksons, Manchester.*]

1873. Jackson, Samuel, C.I.E., Locomotive and Carriage Superintendent, Great Indian Peninsula Railway, Bombay.

1886. Jackson, Thomas, Yorkshire College, Leeds.

1872. Jackson, William Francis, Sterndale House, Litton, near Stockport.

1873. Jacob, Edward Westley, 3 Woodside Terrace, Grange Road, Darlington.

1876. Jacobs, Charles Mattathias, 88 Bishopsgate Street Within, London, E.C. [*Vexillum, London.*]

1878. Jakeman, Christopher John Wallace, Manager, Messrs. Merryweather and Sons, Tram Locomotive Works, Greenwich Road, London, S.E.

1877. James, Christopher, 4 Alexandra Road, Clifton, Bristol.

1877. James, John William Henry, 9 Victoria Chambers, 17 Victoria Street, Westminster, S.W.

1879. Jameson, George, Glencormac, Bray, Ireland.

1881. Jameson, John, Messrs. Jameson and Schaeffer, Akenside Hill, Newcastle-on-Tyne. [*Jameson, Newcastle-on-Tyne.* 226.]

1888. Jaques, Lieut. William Henry, Secretary to Ordnance Committee, United States; and Bethlehem Iron Works, Bethlehem, Pa., United States.

1876. Jebb, George Robert, Engineer to the Shropshire Union Railways and Canal, Birmingham; and Fairyfield, Great Barr, Birmingham.

1888. Jeejeebhoy, Piroshaw Bomanjee, 17 Church Street, Bombay, India.

1861. Jeffcock, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.

1880. Jefferies, John Robert, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich.

1881. Jefferiss, Thomas, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham. [*Tangyes, Birmingham.*]

1863. Jeffreys, Edward A., Monk Bridge Iron Works, Leeds; and Hawkhills, Chapel Allerton, Leeds. [*Gipton, Leeds.* 1614.]

1877. Jeffreys, Edward Homer, 5 Westminster Chambers, 9 Victoria Street, Westminster, S.W.

1884. Jenkins, Alfred, Sirhowy House, Romilly Road, Canton, near Cardiff.

1880. Jenkins, Rhys, Patent Office, 25 Southampton Buildings, London, W.C.

1878. Jensen, Peter, 77 Chancery Lane, London, W.C. [*Venture, London.*]

1886. Jewell, Henry William, Messrs. Jewell and Son, City Foundry, Winchester.

1863. Johnson, Bryan, Hydraulic Engineering Works, Chester; and 34 Kings Buildings, Chester.

1882. Johnson, Charles Malcolm, Inspector of Machinery, Superintending Engineer, H.M. Dockyard, Bermuda; and 11 Napier Street, Stoke, Devonport.

1885. Johnson, John Clarke, Messrs. James Russell and Sons, Crown Tube Works, Wednesbury.

1888. Johnson, Lawrence Potter, Assistant Locomotive Superintendent, Burma State Railway, Insein, British Burma.

1882. Johnson, Samuel, Manager, Globe Cotton and Woollen Machine Works, Rochdale.

1887. Johnson, Samuel Henry, Engineering Works, Carpenter's Road, Stratford, London, E.

1861. Johnson, Samuel Waite, Locomotive Superintendent, Midland Railway, Derby.

1886. Johnson, William, 3 Kirbey Street, Poplar, London, E.

1888. Johnson, William, Castleton Foundry and Engineering Works, Armley Road, Leeds.

1872. Joicey, Jacob Gowland, Messrs. J. and G. Joicey and Co., Forth Banks West Factory, Newcastle-on-Tyne. [*Engines, Newcastle-on-Tyne.*]

1882. Jolin, Philip, 35 Narrow Wine Street, Bristol; and 2 Elmdale Road, Redland, Bristol.

1871. Jones, Charles Henry, Assistant Locomotive Superintendent, Midland Railway, Derby.

1873. Jones, Edward, Messrs. Greenwood and Batley, Albion Works, Leeds; and 13 Blenheim Square, Leeds.

1884. Jones, Felix, Messrs. Jones and Foster, 39 Bloomsbury Street, Birmingham.

1878. Jones, Frederick Robert, Superintending Engineer, Sirmoor State, Nahan, near Umballa, Punjaub, India: (or care of Messrs. Richard W. Jones and Co., Newport, Monmouthshire.)

1867. Jones, George Edward, Assistant Locomotive Superintendent, North Western Railway, Saharunpur, Punjaub, India: (or care of Mrs. Edward Jones, 9 Sydenham Villas, Cheltenham.)

1878. Jones, Harry Edward, Engineer, Commercial Gas Works, Stepney, London, E.

1881. Jones, Herbert Edward, Locomotive Department, Midland Railway, Manchester.

1882. Jones, Samuel Gilbert, Bombay Burmah Trading Corporation, Rangoon, British Burmah: (or care of Messrs. Wallace Brothers, 8 Austin Friars, London, E.C.)

1887. Jones, Thomas, Central Board School, Deansgate, Manchester.

1872. Jones, William Richard Sumption, Rajputana State Railway, Ajmeer, India: (or care of Messrs. Henry S. King and Co., 45 Pall Mall, London, S.W.)

1883. Jordan, Edward, Manager, Cardiff Junction Dry Dock and Engineering Works, Cardiff.

1880. Joy, David, 8 Victoria Chambers, 15 Victoria Street, Westminster, S.W.; and Manor Road House, Beckenham.

1878. Jüngermann, Carl, Maschinenbau Actien Gesellschaft Vulcan, Bredow bei Stettin, Germany.

1884. Justice, Howard Rudulph, 55 and 56 Chancery Lane, London, W.C. [*Syng, London.* 2504.]

1888. Kapteyn, Albert, Westinghouse Brake Co., Canal Road, York Road, King's Cross, London, N.

1882. Keeling, Herbert Howard, Merlewood, Eltham.

1869. Keen, Arthur, Patent Nut and Bolt Works, Smethwick, near Birmingham. [*Globe, Birmingham.*]

1867. Kellett, John, Clayton Street, Wigan.

1873. Kelson, Frederick Colthurst, Angra Bank, Waterloo Park, Waterloo, near Liverpool.

1881. Kendal, Ramsey, Locomotive Department, North Eastern Railway, Gateshead.

1879. Kennedy, Alexander Blackie William, F.R.S., Professor of Engineering, University College, Gower Street, London, W.C.; and 3 Prince's Street, Westminster, S.W.

1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway, 45 Finsbury Circus, London, E.C.; and 29 Lupus Street, St. George's Square, London, S.W.

1868. Kennedy, Thomas Stuart, Parkhill, Wetherby.

1875. Kenrick, George Hamilton, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich; and Whetstone, Somerset Road, Edgbaston, Birmingham.

1888. Kershaw, Frederic, Locomotive Carriage and Wagon Superintendent, North West Argentine Railway; La Madrid, Ferro Carril National Central Norte, Argentine Republic.

1866. Kershaw, John, Marazion, St. Leonard's-on-Sea.

1884. Kershaw, Thomas Edward, Chilvers Coton Foundry, Nuneaton.

1887. Key, Alexander, Superintendent Engineer, Bedouin Steam Navigation Co., Mersey Chambers, Liverpool.

1885. Keydell, Amandus Edmund, Lloyd's Register of Shipping, Dundee.

1885. Keyworth, Thomas Egerton, Ferro Carril Buenos Aires y Rosario, Campana, Buenos Aires, Argentine Republic.

1885. Kidd, Hector, Colonial Sugar Refining Co., Sydney, New South Wales.

1888. Kikuchi, Kyozo, Superintendent Engineer, Hirano Spinning Mill, Osaka, Japan.

1872. King, William, Engineer, Liverpool United Gas Works, Duke Street, Liverpool.

1872. Kirk, Alexander Carnegie, LL.D., Messrs. Robert Napier and Sons, Lancefield House, Glasgow; and Govan Park, Govan, Glasgow.

1877. Kirk, Henry, Messrs. Kirk Brothers and Co., New Yard Iron Works, Workington. [*Kirks, Workington.*]

1884. Kirkaldy, John, 40 West India Dock Road, London, E. [*Compactum, London.*]

1875. Kirkwood, James, Chief Inspector of Machinery for Pei Yang Squadron; care of Imperial Maritime Customs, Chefoo, China; and Melita Cottage, Denny.

1864. Kirtley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.W. [3005.]

1859. Kitson, Sir James, Bart., Monk Bridge Iron Works, Leeds.
1868. Kitson, John Hawthorn, Airedale Foundry, Leeds. [*Airedale, Leeds.*]
1874. Klein, Thorvald, Suffolk House, 5 Laurence Pountney Hill, London, E.C.
1886. Knight, Charles Albert, Babcock and Wilcox Boiler Co., 107 Hope Street, Glasgow.

1881. Laing, Arthur, Deptford Shipbuilding Yard, Sunderland.
1872. Laird, Henry Hyndman, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.
1872. Laird, William, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.
1883. Lake, William Robert, 45 Southampton Buildings, London, W.C. [*Scopo, London.*]
1878. Lambourn, Thomas William, Naughton Hall, near Bildeston, S.O., Suffolk.
1881. Langdon, William, Locomotive Superintendent and Chief Mechanical Engineer, Rio Tinto Railway and Mines, Huelva, Spain: (or care of T. C. Langdon, Tamar Terrace, Launceston.)
1881. Lange, Frederick Montague Townshend, Messrs. Lange's Wool-Combing Works, Saint Acheul-les-Amiens, Somme, France.
1877. Lange, Hermann Ludwig, Manager, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.
1879. Langley, Alfred Andrew, Engineer-in-Chief, Midland Railway, Derby.
1879. Lapage, Richard Herbert, 17A Great George Street, Westminster, S.W. [*Lapage, London.*]
1879. Larsen, Jorgen Daniel, 10 Tudor Road, Upper Norwood, London, S.E.
1888. Latham, Baldwin, 7 Westminster Chambers, 13 Victoria Street, Westminster, S.W.
1881. Lavalley, Alexander, 48 Rue de Provence, Paris.
1867. Lawrence, Henry, The Grange Iron Works, Durham.
1874. Laws, William George, Borough Engineer and Town Surveyor, Town Hall, Newcastle-on-Tyne; and 5 Winchester Terrace, Newcastle-on-Tyne. [*Engineer, Newcastle-on-Tyne.*]
1882. Lawson, Frederick William, Messrs. Samuel Lawson and Sons, Hope Foundry, Leeds.
1870. Layborn, Daniel, Messrs. Caine and Layborn, Dutton Street, Liverpool.
1883. Laycock, William S., Messrs. Samuel Laycock and Sons, Horse-hair Cloth Works, Sheffield; and Ranmoor, Sheffield.
1860. Lea, Henry, Messrs. Henry Lea and Thornbery, 38 Bennett's Hill, Birmingham. [*Engineer, Birmingham.* 113.]

1883. Leavitt, Erasmus Darwin, Jun., 604 Main Street, Cambridgeport, Massachusetts, United States.

1865. Ledger, Joseph, Keswick.

1886. Lee, Charles Eyre, 18 Newhall Street, Birmingham.

1887. Lee, Cuthbert Ridley, Messrs. J. Coates and Co., 106 Cannon Street, London, E.C.

1862. Lee, J. C. Frank, 9 Park Crescent, Portland Place, London, W.

1871. Lee, William, Messrs. Lee Clerk and Robinson, Gospel Oak Iron Works, Tipton; and 110 Cannon Street, London, E.C.

1863. Lees, Samuel, Messrs. H. Lees and Sons, Park Bridge Iron Works, Ashton-under-Lyne.

1883. Lennox, John, 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W.

1882. Léon, Auguste, Locomotive Engineer, Chemins de fer de Paris à Lyon et à la Méditerranée, 220 Boulevard Voltaire, Paris.

1858. Leslie, Andrew, Coxlodge Hall, Newcastle-on-Tyne.

1888. Leslie, Sir Bradford, K.C.I.E., Tarrangower, Willesden Lane, Brondesbury, London, N.W.

1883. Leslie, Joseph, Marine Engineer, Messrs. Apcar and Co., Raddah Bazar, Calcutta.

1878. Lewis, Gilbert, Manager, New Bridge Foundry, Adelphi Street, Salford, Manchester.

1884. Lewis, Henry Watkin, Llwyn-yr-eos, Abercanaid, near Merthyr Tydfil.

1872. Lewis, Richard Amelius, Messrs. John Spencer and Sons, Tyne Hæmatite Iron Works, Scotswood-on-Tyne.

1887. Lewis, Rowland Watkin, Messrs. Edwin Lewis and Sons, Britannia Boiler Tube Works, Wolverhampton.

1884. Lewis, Sir William Thomas, Bute Mineral Estate Office, Aberdare; and Mardy, Aberdare.

1880. Lightfoot, Thomas Bell, Cornwall Buildings, 35 Queen Victoria Street, London, E.C. [*Separator, London.*]; and 7 Eastcombe Villas, Charlton Road, Blackheath, London, S.E.

1887. Lindsay, Joseph, Messrs. Urquhart Lindsay and Co., Blackness Foundry, Dundee.

1856. Linn, Alexander Grainger, 121 Upper Parliament Street, Liverpool.

1876. Lishman, Thomas, Mining Engineer, Hetton Colliery, near Fence Houses.

1881. List, John, Superintendent Engineer, Messrs. Donald Currie and Co., Orchard Works, Blackwall, London, E.

1885. Lister, Frank, Messrs. Wilkinson and Lister, Bradford Road Works, Keighley.

1887. Litster, David Michael, Executive Engineer, Public Works Department, India; care of Messrs. Grindlay and Co., 55 Parliament Street, Westminster, S.W.

1866. Little, George, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1867. Livesey, James, 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W.

1886. Livsey, John Edward, Demonstrator in Mechanics and Mathematics, Normal School of Science, South Kensington, London, S.W.

1867. Lloyd, Charles, New Athenæum Club, 26 Suffolk Street, Pall Mall, London, S.W.

1871. Lloyd, Francis Henry, James Bridge Steel Works, near Wednesbury [*Steel, Wednesbury*]; and Wood Green, Wednesbury.

1854. Lloyd, George Braithwaite (*Life Member*), Edgbaston Grove, Birmingham.

1882. Lloyd, Robert Samuel, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1852. Lloyd, Samuel, The Farm, Sparkbrook, Birmingham.

1879. Lockhart, William Stronach, Fenchurch House, 7 Fenchurch Street, London, E.C.

1881. Lockyer, Norman Joseph, care of Sir A. M. Rendel, 8 Great George Street, Westminster, S.W.

1884. Logan, Andrew Linton, Vulcan Foundry, Newton-le-Willows, Lancashire.

1883. Logan, Robert Patrick Tredennick, Engineer's Office, Great Northern Railway of Ireland, Dundalk.

1874. Logan, William, Mining Engineer, Langley Park Colliery, Durham.

1884. Longbottom, Luke, Locomotive Carriage and Wagon Superintendent, North Staffordshire Railway, Stoke-on-Trent.

1885. Longden, John Needham, Mining Engineer, Messrs. W. Pritchard-Morgan and Co., 1 Queen Victoria Street, London, E.C.

1880. Longridge, Michael, Chief Engineer, Engine and Boiler Insurance Co., 12 King Street, Manchester.

1856. Longridge, Robert Bewick, Managing Director, Engine and Boiler Insurance Co., 12 King Street, Manchester; and Yew Tree House, Tabley, near Knutsford.

1875. Longridge, Robert Charles, Kilrie, Knutsford.

1880. Longworth, Daniel, Carnac Iron Works, Bombay.

1887. Lorrain, James Grieve, Norfolk House, Norfolk Street, London, W.C. [*Lorrain, London.*]

1888. Low, David Allan, Lecturer on Engineering, The People's Palace Technical Schools, Mile End Road, London, E.

1861. Low, George, Bishop's Hill Cottage, Ipswich.

1885. Low, Robert, Eildon House, Macaulay Road, Clapham Common, London, S.W.

1884. Lowcock, Arthur, Coleham Foundry, Shrewsbury.

1884. Lowdon, John, General Manager, Barry Graving Dock and Engineering Co., Exchange Buildings, Cardiff. [*Bardock, Cardiff.*]

1873. Lowe, John Edgar, Messrs. Bolling and Lowe, 2 Laurence Pountney Hill, London, E.C. [*Bird, London.* 1530.]

1883. Lowe, Sutton Harvey, Eastgate House, Lincoln.

1887. Loynd, John Shaw, Messrs. Clayton Goodfellow and Co., Atlas Works, Park Road, Blackburn.

1873. Lucas, Arthur, 15 George Street, Hanover Square, London, W.

1877. Lupton, Arnold, Professor of Mining Engineering, Yorkshire College, Leeds; and 6 De Grey Road, Leeds. [*Arnold Lupton, Leeds.* 330.]

1887. Lupton, Kenneth, 6 Gordon Terrace, Cope Street, Coventry.

1878. Lynde, James Henry, 32 St. Ann's Street, Manchester.

1888. Macbeth, John Bruce King, 44 Tamarind Lane, Bombay, India: (or care of Norman Macbeth, Heaton, Bolton.)

1883. Macbeth, Norman, Messrs. John and Edward Wood, Victoria Foundry, Bolton.

1884. MacCarthy, Samuel, 6 Endwell Road, Brockley, London, S.E.

1877. MacColl, Hector, Messrs. MacIlwaine and MacColl, Ulster Iron Works, Belfast.

1879. Macdonald, Augustus Van Zundt, District Manager, New Zealand Railways, Napier, New Zealand.

1885. Mackenzie, John William, Messrs. Wheatley and Mackenzie, 156 Strand, London, W.C.; and Northfield, Oxford Road, Upper Teddington, S.O., Middlesex.

1875. Maclagan, Robert, care of Dr. Maclagan, 9 Cadogan Place, Belgrave Square, London, S.W.

1886. MacLean, Alexander Scott, Messrs. Alexander Scott and Sons, Sugar Refinery, Berry-yards, Greenock.

1877. MacLellan, John A., Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow. [*Alley, Glasgow.* 673.]

1888. Macleod, Arthur William, Messrs. John Fowler and Co., 5 Mangoe Lane, Calcutta, India.

1864. Macnab, Archibald Francis, Inspecting and Examining Engineer, Government Marine Office, Tokio, Japan.

1865. Macnee, Daniel, 2 Westminster Chambers, 3 Victoria Street, Westminster, S.W. [*Macnee, London.*]; and Rotherham.

1884. Macpherson, Alexander Sinclair, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1879. Maginnis, James Porter, 9 Carteret Street, Queen Anne's Gate, Westminster, S.W. [*James Maginnis, London.*]

1873. Mair, John George, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W. [*Screwcock, London.*]

1884. Mais, Henry Coathupe, 29 Queen Street, Melbourne, Victoria.

1888. Maitland, Eardley, Major-General, R.A., Director General Ordnance Factories, Royal Arsenal, Woolwich; and 35 Grove End Road, St. John's Wood, London, N.W.

1879. Malcolm, Bowman, Locomotive Superintendent, Belfast and Northern Counties Railway, Belfast.

1888. Mano, Bunji, Japanese Legation, 9 Cavendish Square, London, W.

1875. Mansergh, James, 3 Westminster Chambers, 5 Victoria Street, Westminster, S.W.

1862. Mappin, Sir Frederick Thorpe, Bart., M.P., Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield; and Thornbury, Sheffield.

1857. March, George, Messrs. Maclea and March, Union Foundry, Dewsbury Road, Leeds. [*Maclea, Leeds.*]

1878. Marié, Georges, Engineer, Chemins de fer de Paris à Lyon et à la Méditerranée, Bureaux du Matériel, Boulevart Mazas, Paris.

1856. Markham, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield; and Tapton House, Chesterfield.

1888. Marks, George Croydon, 13 Temple Street, Birmingham. [*Pumps, Birmingham.*]

1884. Marquand, Augustus John, Pierhead Chambers, Cardiff.

1887. Marriott, William, Engineer and Locomotive Superintendent, Eastern and Midlands Railway, Melton Constable, Norfolk.

1887. Marsden, Benjamin, Messrs. S. Marsden and Son, Screw-Bolt and Nut Works, London Road, Manchester.

1871. Marsh, Henry William, Winterbourne, near Bristol.

1875. Marshall, Alfred (*Life Member*), 13 Ferron Road, Clapton, London, E.

1865. Marshall, Francis Carr, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1885. Marshall, Henry Dickenson, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough. [*Marshalls, Gainsborough.* 6648.]

1871. Marshall, James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough. [*Marshalls, Gainsborough.* 6648.]

1885. Marshall, Jenner Guest, Westcott Barton Manor, Oxfordshire.

1877. Marshall, William Bayley, 15 Augustus Road, Birmingham. [*Augustus, Birmingham.*]

1847. Marshall, William Prime, 15 Augustus Road, Birmingham. [*Augustus, Birmingham.*]

1859. Marten, Edward Bindon, Chief Engineer, Midland Steam Boiler Inspection and Assurance Company, 56 Hagley Street, Stourbridge [*Marten, Stourbridge.*]; Pedmore, Stourbridge; and 4 Storey's Gate, Westminster, S.W.

1853. Marten, Henry John, The Birches, Codsall, near Wolverhampton; and 4 Storey's Gate, Westminster, S.W.

1881. Martin, Edward Pritchard, Dowlais Iron Works, Dowlais.

1878. Martin, Henry, Hanwell, Middlesex, W.

1888. Martin, Henry James, Castle Foundry and Engineering Works, Strand, Swansea; and Tresleigh House, Walters Road, Swansea.

1880. Martin, Robert Frewen, Mount Sorrel Granite Co., Loughborough.

1886. Martin, William Hamilton, Engineering Manager, The Scheldt Royal Shipbuilding and Engineering Works, Flushing, Holland.

1882. Masefield, Robert, Manor Iron Works, Manor Street, Chelsea, London, S.W.

1884. Massey, George, Foy's Chambers, Bond Street, Sydney, New South Wales. [*Masseybond, Sydney.*]

1876. Mather, John, 4 Great George Street, Westminster, S.W. [3002]; and 23 Devonshire Road, South Lambeth, London, S.W.

1867. Mather, William, Messrs. Mather and Platt, Salford Iron Works, Manchester. [*Mather, Manchester.*]

1883. Mather, William Penn, Messrs. Mather and Platt, Salford Iron Works, Manchester. [*Mather, Manchester.*]

1882. Matheson, Henry Cripps, care of Messrs. Russell and Co., Hong Kong, China: (or care of Messrs. Matheson and Grant, 32 Walbrook, London, E.C.)

1875. Matthews, James, 22 Ashfield Terrace East, Newcastle-on-Tyne.

1886. Matthews, Robert, Parrs House, Heaton Mersey, near Manchester.

1875. Mattos, Antonio Gomes de, Messrs. Maylor and Co., Engineering Works, 136 Rua da Saude, Rio de Janeiro, Brazil: (or care of Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.)

1853. Maudslay, Henry (*Life Member*), Westminster Palace Hotel, 4 Victoria Street, Westminster, S.W.: (or care of John Barnard, 47 Lincoln's Inn Fields, London, W.C.)

1869. Maughan, Thomas, Engineer, Cramlington Colliery, Cramlington, Northumberland.

1873. Maw, William Henry, 35 Bedford Street, Strand, London, W.C. [3663.]

1884. Maxim, Hiram Stevens, 57D Hatton Garden, London, E.C. [*Maxim, London.* 6507.]

1859. Maylor, William, Brooklyn, Hayne Road, Beckenham.

1874. McClean, Frank, Norfolk House, Norfolk Street, Strand, London, W.C.

1872. McConnochie, John, Engineer to the Bute Harbour Trust, 16 Bute Crescent, Bute Docks, Cardiff.

1878 McDonald, John Alexander, Assistant Engineer for Roads and Bridges, Public Works Office, Sydney, New South Wales: (or care of James E. McDonald, 4 Chapel Street, Cripplegate, London, E.C.)

1865. McDonnell, Alexander, 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W.; and Wellesley, Warlingham, S.O., Surrey.

1881. McGregor, Josiah, Crown Buildings, 78 Queen Victoria Street, London, E.C. [*Sahib, London.*]

1881. McKay, John, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1880. McLachlan, John, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley. [*Bow, Paisley.*]

1888. McLaren, Henry, Messrs. J. and H. McLaren, Midland Engine Works, Leeds.

1882. McLaren, Raynes Lauder, 6 Grote's Place, Blackheath, London, S.E.

1888. McLarty, Farquhar Matheson, Penang Foundry, Penang: (or care of William Bow, Thistle Engine Works, Paisley.)

1879. McLean, William Leckie Ewing, Lancefield Forge Co., Glasgow.

1885. McNeil, John, Messrs. Aitken McNeil and Co., Helen Street, Govan, Glasgow. [*Colonial, Govan.*]

1882. Meats, John Tempest, Mason Machine Works, Taunton, Massachusetts, United States.

1863. Meek, Sturges, Consulting Engineer, Lancashire and Yorkshire Railway, Manchester; and Dunstall Lodge, 18 Holland Villas Road, London, W.

1881. Meik, Charles Scott, care of H.B.M. Consul, Yokohama, Japan: (or care of P. Walter Meik, 16 Victoria Street, Westminster, S.W.)

1858. Meik, Thomas, 21 York Place, Edinburgh.

1887. Melhuish, Frederick, Assistant Engineer, Southwark and Vauxhall Water Works, 68 Sumner Street, Southwark, London, S.E.

1888. Melville, William Wilkie, 20 Buchanan Road, Seacombe, R.O., near Birkenhead.

1878. Menier, Henri, 56 Rue de Châteaudun, Paris.

1876. Menzies, William, Messrs. Menzies and Co., 50 Side, Newcastle-on-Tyne.

1875. Merryweather, James Compton, Messrs. Merryweather and Sons, Fire-Engine Works, Greenwich Road, London, S.E.; and 63 Long Acre, London, W.C. [*Merryweather, London.*]

1881. Meysey-Thompson, Arthur Herbert, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds.

1877. Michele, Vitale Domenico de, 14 Delahay Street, Westminster, S.W.; and Higham Hall, Rochester.

1884. Middleton, Reginald Empson, 49 Parliament Street, Westminster, S.W.

1886. Midelton, Thomas, Locomotive Engineer, New South Wales Government Railways, Sydney, New South Wales.

1862. Miers, Francis C., Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.; and Eden Cottage, West Wickham Road, Beckenham. [*Foundation, London.* 1920.]

1864. Miers, John William, 74 Addison Road, Kensington, London, W.

1874. Milburn, John, Hawkshead Foundry, Quay Side, Workington.

1887. Miles, Frederick Blumenthal, Messrs. Bement Miles and Co., Callowhill and Twenty-first Streets, Philadelphia, United States.

1885. Miller, Harry William, care of Messrs. Chester and Gibb, Johannesburg, Transvaal, South Africa.

1886. Miller, John Smith, Messrs. Smith Brothers and Co., Hyson Green Works, Nottingham.

1887. Miller, Thomas Lodwick, University College, Liverpool.

1885. Millis, Charles Thomas, Technical College, Finsbury, London, E.C.

1887. Milne, William, Locomotive Superintendent, Natal Government Railways, Natal.

1856. Mitchell, Charles, Sir W. G. Armstrong Mitchell and Co., Low Walker, Newcastle-on-Tyne; and Jesmond Towers, Newcastle-on-Tyne.

1870. Moberly, Charles Henry, Messrs. Easton and Anderson, Erith Iron Works, Erith, S. O., Kent.

1885. Moir, James, Superintendent Engineer, Bombay Steam Navigation Co., Frere Road, Bombay.

1879. Molesworth, Sir Guilford Lindsay, K.C.I.E., Consulting Engineer to the Government of India for State Railways, Supreme Government, India.

1882. Molesworth, James Murray, Spotland Vicarage, Rochdale: (or care of Messrs. Price and Belsham, 52 Queen Victoria Street, London, E.C.)

1881. Molinos, Léon, 48 Rue de Provence, Paris.

1885. Monk, Edwin, care of Josiah McGregor, Crown Buildings, 78 Queen Victoria Street, London, E.C.

1884. Monroe, Robert, Manager, Penarth Slipway and Engineering Works, Penarth Dock, Penarth.

1872. Moon, Richard, Jun., Penyvoel, Llanymynech, Montgomeryshire.

1884. Moore, Benjamin Theophilus, Longwood, Bexley, S. O., Kent.

1876. Moore, Joseph, Risdon Iron and Locomotive Works, San Francisco, California; 6 Durham Road, East End, Finchley, London, N.: (or care of Ralph Moore, Government Inspector of Mines, Rutherglen, Glasgow.)

1882. Moore, Richard St. George, Messrs. Clarke and Moore, 9 Victoria Chambers, 17 Victoria Street, Westminster, S.W.

1872. Moorsom, Warren Maude, Belvidere, Park Road, West Dulwich, London, S.E.

1880. Moreland, Richard, Jun., Messrs. Richard Moreland and Son, 3 Old Street, St. Luke's, London, E.C. [*Expansion, London.*]

1885. Morgan, Thomas Rees, Morgan Engineering Works, Alliance, Ohio, United States.

1887. Morison, Donald Barns, Messrs. T. Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1888. Morris, Charles, 5 Mangoe Lane, Calcutta, India.

1874. Morris, Edmund Legh, New River Water Works, Finsbury Park, London, N.

1885. Morse, Harold, care of Sydney Morse, 5 Lime Street Square, London, E.C.: (or Park, Nottingham.)

1858. Mountain, Charles George, Eagle Foundry, Broad Street, Birmingham.

1886. Mountain, William Charles, Messrs. Ernest Scott and Co., Close Works, Newcastle-on-Tyne; and 9 St. George's Terrace, Jesmond, Newcastle-on-Tyne.

1884. Mower, George A., Crosby Steam Gage and Valve Co., 75 Queen Victoria Street, London, E.C. [*Crosby, London.*]

1885. Mudd, Thomas, Manager, Messrs. William Gray and Co., Central Marine Engineering Works, West Hartlepool.

1873. Muir, Alfred, Messrs. William Muir and Co., Britannia Works, Sherborne Street, Strangeways, Manchester.

1873. Muir, Edwin, 37 Cross Street, Manchester. [1027.]

1863. Muir, William, 2 Walbrook, London, E.C.; and 143 Brockley Road, New Cross, London, S.E.

1876. Muirhead, Richard, Messrs. Drake and Muirhead, Maidstone.

1881. Musgrave, James, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton. [*Musgrave, Bolton.*]

1863. Musgrave, John, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton. [*Musgrave, Bolton.*]

1882. Musgrave, Walter Martin, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton. [*Musgrave, Bolton.*]

1888. Myers, William Beswick, 14 Victoria Street, Westminster, S.W.

1870. Napier, James Murdoch, Messrs. David Napier and Son, Vine Street, York Road, Lambeth, London, S.E.

1888. Nathan, Adolphus, Messrs. Larini Nathan and Co., Milan; and 15 Via Bigli, Milan, Italy.

1861. Naylor, John William, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1883. Neate, Percy John, 16 The Banks, High Street, Rochester.

1863. Neilson, Walter Montgomerie, Clyde Locomotive Works, Glasgow; and Queen's Hill, Ringford, Kirkcudbrightshire.

1884. Nelson, John, 48 Bootham, York.

1887. Nelson, Sidney Herbert, Messrs. Samuel Worssam and Co., Oakley Works, King's Road, Chelsea, London, S.W.

1881. Nesfield, Arthur, 7 Rumford Street, Liverpool.

1882. Nettlefold, Hugh, Screw Works, 16 Broad Street, Birmingham. [*Nettlefolds, Birmingham.*]

1879. Newall, Robert Stirling, F.R.S., Wire Rope Works, Gateshead; and Ferndene, Gateshead.

1866. Newdigate, Albert Lewis (*Life Member*), Engineer's Office, Dover Harbour, Dover.

1882. Nicholl, Edward McKillop, Bengal Public Works Department, Amritsar, Punjaub, India: (or care of Messrs. Henry S. King and Co., 65 Cornhill, London, E.C.)

1884. Nicholls, James Mayne, East Street, Bridport.

1884. Nicholson, Henry, care of G. H. Hill, Albert Chambers, Albert Square, Manchester.

1877. Nicolson, Donald, Elsden Lodge, 112 Burnt Ash Road, Lee, London, S.E.

1886. Noakes, Thomas Joseph, Messrs. Thomas Noakes and Sons, 35 and 37 Brick Lane, Whitechapel, London, E.

1884. Noakes, Walter Maplesden, 43 York Street, Wynyard Square, Sydney, New South Wales.

1882. Nordenfelt, Thorsten, 53 Parliament Street, Westminster, S.W.

1868. Norris, William Gregory, Coalbrookdale Iron Works, Coalbrookdale, Shropshire.

1883. North, Gamble, Messrs. North and Jewel, Peruano Nitrate of Soda and Iodine Works, Iquique, Chile: (or care of John T. North, Avery House, Avery Hill, Eltham.)

1882. North, John Thomas, Messrs. North Humphrey and Dickenson, Engineering Works, Iquique, Chile; and Avery House, Avery Hill, Eltham.

1878. Northcott, William Henry, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E.; and 7 St. Mary's Road, Peckham, London, S.E. [*Oxygen, London.* 8007.]

1888. Norton, William Eardley, 8 Great George Street, Westminster, S.W.

1882. Nunneley, Thomas, 9 Beech Grove Terrace, Leeds.

1885. Oakes, Sir Reginald Louis, Bart., York Engineering Works, Leeman Road, York.

1887. O'Brien, Benjamin Thompson, 47 Kingsley Road, Liverpool.
1887. O'Brien, John Owden, Messrs. W. P. Thompson and Co., Ducie Buildings, 6 Bank Street, Manchester.
1868. O'Connor, Charles, 5 Welfield Place, Dingle, Liverpool.
1888. O'Donnell, John Patrick, London and South Western Railway, Wimbledon Station, Wimbledon; and Cambridge Road, New Malden, S.O., Surrey.
1887. O'Flyn, John Lucius, Messrs. L. and H. Guéret and Co., Exchange, Cardiff.
1886. Ogle, Percy John, 4 Bishopsgate Street Within, London, E.C.
1875. Okes, John Charles Raymond, 39 Queen Victoria Street, London, E.C. [*Oaktree, London.*]
1887. Oliver, Hedley, 6 Park Hill Road, Harborne, Birmingham.
1882. Orange, James, Surveyor General's Department, Hong Kong, China: (or care of Mrs. Mary Orange, 2 West End Terrace, Jersey.)
1885. Ormerod, Richard Oliver, 35 Philbeach Gardens, South Kensington, London, S.W.
1870. Osborn, Samuel, Clyde Steel and Iron Works, Sheffield. [*Osborn, Sheffield.*]
1867. Oughterson, George Blake, care of Peter Brotherhood, Belvedere Road, Lambeth, London, S.E.
1886. Owen, Thomas Henry, 200 Newport Road, Cardiff.

1868. Paget, Arthur, Loughborough. [*Paget Company, Loughborough.*]
1877. Panton, William Henry, General Manager, Stockton Forge, Stockton-on-Tees. [*Forge, Stockton-on-Tees.*]
1877. Park, John Carter, Locomotive Engineer, North London Railway, Bow, London, E.
1871. Parke, Frederick, Withnell Fire Clay Works, near Chorley.
1872. Parker, Thomas, Locomotive Carriage and Wagon Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.
1888. Parker, Thomas, Jun., Locomotive Department, Manchester Sheffield and Lincolnshire Railway, Gorton, Manchester.
1879. Parker, William, Chief Engineer Surveyor, Lloyd's Register, 2 White Lion Court, Cornhill, London, E.C.
1871. Parkes, Persehouse, care of Messrs. Henry Persehouse Parkes and Co., 7 Goree Piazzas, Liverpool. [*Persehouse, Liverpool.*]
1884. Parlane, William, Hong Kong Ice Works, Eastpoint, Hong Kong, China.
1886. Parry, Alfred, Messrs. Balmer Lawrie and Co., 103 Clive Street, Calcutta, India.
1878. Parsons, The Hon. Richard Clere, Oak Lea, Wimbledon Park, Surrey.

1886. Passmore, Frank Bailey, 47 Cannon Street, London, E.C. [*Knarf, London.*]

1880. Paterson, Walter Saunders, Bombay Burmah Trading Corporation, Rangoon, British Burmah, India : (or care of Messrs. Wallace Brothers, 8 Austin Friars, London, E.C.)

1877. Paton, John McClure Caldwell, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Ilkeston Road, Nottingham. [*Manloves, Nottingham.*]

1881. Patterson, Anthony, Dowlais Iron Works, Dowlais.

1883. Pattison, Giovanni, Messrs. C. and T. T. Pattison, Engineering Works, Naples. [*Pattison, Naples.*]

1872. Paxman, James Noah, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester. [*Paxman, Colchester.*]

1880. Peache, James Courthope, Messrs. Willans and Robinson, Ferry Works, Thames Ditton.

1869. Peacock, Ralph, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1869. Peacock, Ralph, Aire and Calder Foundry, Goole.

1847. Peacock, Richard, M.P., Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester; and Gorton Hall, Gorton, near Manchester.

1879. Pearce, George Cope, Ryefields, Ross.

1873. Pearce, Richard, Deputy Carriage and Wagon Superintendent, East Indian Railway, Howrah, Bengal, India.

1867. Pearce, Robert Webb, Carriage Superintendent, East Indian Railway, Howrah, Bengal, India; and 47 Gunterstone Road, West Kensington, London, W.

1884. Pearson, Frank Henry, Earle's Shipbuilding and Engineering Works, Hull.

1885. Pearson, Henry William, Engineer, Bristol Water Works, Small Street, Bristol.

1870. Pearson, Thomas Henry, Moss Side Iron Works, Ince, near Wigan.

1883. Peck, Walter, care of Messrs. J. H. Peck and Co., Wallgate, Wigan.

1888. Peel, Charles Edmund, Quay Parade, Swansea.

1884. Penn, George Williams, Lloyd's Bute Proving House, Cardiff.

1873. Penn, John, Messrs. John Penn and Sons, Marine Engineers, Greenwich, London, S.E.

1873. Penn, William, Messrs. John Penn and Sons, Marine Engineers, Greenwich, London, S.E.

1874. Pepper, Joseph Ellershaw, Clarence Iron Works, Leeds.

1874. Percy, Cornelius McLeod, King Street, Wigan.

1861. Perkins, Loftus, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.

1879. Perkins, Stanhope, Healey Terrace, Fairfield, near Manchester.

1882. Perry, Alfred, Messrs. Chance Brothers and Co., Lighthouse Works, near Birmingham.

1865. Perry, William, Claremont Place, Wednesbury.

1882. Petherick, Vernon, care of Messrs. Brown and David, Australian Chambers, Queen Street, Brisbane, Queensland : (or care of Messrs. Hughes Pye and Rigby, Moray Street, Melbourne, Victoria.)

1881. Philipson, John, Messrs. Atkinson and Philipson, Carriage Manufactory, 15 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 415.]

1885. Phillips, Charles David, Emlyn Engineering Works, Newport, Monmouthshire. [*Machinery, Newport, Mon.*]

1885. Phillips, Henry Parnham, Assistant Locomotive Superintendent, Burma State Railway, Insein, British Burma.

1878. Phillips, John, Manager, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.; and 84 Blackfriars Road, London, S.E.

1885. Phillips, Lionel, Mining Engineer, Bultfontein Diamond Mine, Kimberley, South Africa; and Consolidated Co., 29 and 30 Holborn Viaduct, London, E.C.

1879. Phillips, Robert Edward, Royal Courts Chambers, 70 and 72 Chancery Lane, London, W.C.; and Rochelle, Selhurst Road, South Norwood, London, S.E. [*Phicycle, London.*]

1882. Phipps, Christopher Edward, Deputy Locomotive Superintendent, Madras Railway, Perambore Works, Madras.

1876. Piercy, Henry James Taylor, Messrs. Piercy and Co., Broad Street Engine Works, Birmingham. [*Piercy, Birmingham.* 20.]

1877. Pigot, Thomas Francis, Professor of Engineering, Royal College of Science for Ireland, Dublin.

1883. Pillow, Edward, London and North Western Railway, Locomotive Department, Crewe.

1876. Pinel, Charles Louis, Messrs. Lethuillier and Pinel, 26 Rue Meridienne, Rouen, France. [*Lethuillier Pinel, Rouen.*]

1888. Pirrie, Norman, Messrs. Kuhnt and Deissler, 38 Alexander Strasse, Berlin.

1888. Pirrie, William James, Messrs. Harland and Wolff, Belfast.

1883. Pitt, Walter, Messrs. Stothert and Pitt, Newark Foundry, Bath. [*Stothert, Bath.*]

1887. Place, John, Jun., The Bank, Church Street, Mansfield.

1871. Platt, James, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester. [*Atlas, Gloucester.*]

1883. Platt, James Edward, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1867. Platt, Samuel Radcliffe, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1878. Platts, John Joseph, Resident Engineer, Odessa Water Works, Odessa, Russia.

1869. Player, John, Clydach Foundry, near Swansea.

1888. Pogson, Joseph, Manager and Engineer, Huddersfield Corporation Tramways, Huddersfield.

1886. Pollock, James, Fenchurch House, 5 and 7 Fenchurch Street, London, E.C. [*Specific, London.*]

1876. Pollock, Julius Frederick Moore, Messrs. Pollock and Pollock, Longclose Works, Newtown, Leeds.

1876. Pooley, Henry, Messrs. Henry Pooley and Son, Albion Foundry, Liverpool. [*Pooley, Liverpool.*]

1864. Potts, Benjamin Langford Foster, 55 Chancery Lane, London, W.C.; and 5 Camden Row, Camberwell, London, S.E.

1878. Powell, Henry Coke, care of Thomas Powell, 23 Rue St. Julien, Rouen, France: (or care of C. M. Roffe, 1 Bedford Row, London, W.C.)

1870. Powell, Thomas (Son), Messrs. Thomas and T. Powell, 23 Rue St. Julien, Rouen, France.

1874. Powell, Thomas (Nephew), Brynhyfryd, Neath.

1867. Pratchitt, John, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1865. Pratchitt, William, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1885. Pratten, William John, Messrs. Harland and Wolff, Belfast.

1882. Presser, Ernest Charles Antoine, 4 Salesas, Madrid.

1856. Preston, Francis, Netherfield House, Kirkburton, near Huddersfield. [*Preston, Kirkburton.*]

1877. Price, Henry Sherley, Messrs. Wheatley Kirk, Price, and Goulty, 52 Queen Victoria Street, London, E.C. [*Indices, London.* 1533.]

1866. Price, John, General Manager, Messrs. Palmer's Shipbuilding and Iron Works, Jarrow; and 6 Osborne Villas, Jesmond, Newcastle-on-Tyne.

1859. Price-Williams, Richard, 38 Parliament Street, Westminster, S.W.

1874. Prosser, William Henry, Messrs. Harfield and Co., Blaydon-on-Tyne.

1885. Pudan, Oliver, Fuel-Gas and Electric Engineering Works, Twenty-fifth and Liberty Streets, Pittsburgh, Pennsylvania, U.S.: (or 15 Princes Street, Yeovil).

1884. Puplett, Samuel, 5 Thornbury Road, Clapham Park, London, S.W.

1866. Putnam, William, Darlington Forge, Darlington.
1887. Pyne, Thomas Salter, care of H.H. the Ameer of Afghanistan, Cabul; care of Messrs. Walsh Lovett and Co., 10 Ludgate Hill, Birmingham.

1878. Quillacq, Augustus de, Société anonyme de Constructions mécaniques d'Anzin, Anzin (Nord), France.

1870. Radcliffe, William, Camden House, 25 Collegiate Crescent, Sheffield.
1878. Radford, Richard Heber, 15 St. James' Row, Sheffield.
1868. Rafarel, Frederic William, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.
1884. Rafarel, William Claude, Barnstaple Foundry and Engineering Works, Victoria Road, Barnstaple. [*Rafarel, Barnstaple.*]
1885. Rainforth, William, Jun., Britannia Iron Works, Lincoln. [*Rainforths, Lincoln.*]
1878. Rait, Henry Milnes, Messrs. Rait and Gardiner, 155 Fenchurch Street, London, E.C. [*Repairs, London.*]
1847. Ramsbottom, John, Fernhill, Alderley Edge, Cheshire.
1866. Ramsden, Sir James, Abbot's Wood, Barrow-in-Furness.
1860. Ransome, Allen, 304 King's Road, Chelsea, London, S.W. [*Ransome, London.*]
1886. Ransome, James Edward, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich. [*Ransomes, Ipswich.*]
1862. Ransome, Robert James, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich. [*Waterside, Ipswich.*]
1873. Rapier, Richard Christopher, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich; and 5 Westminster Chambers, 9 Victoria Street, Westminster, S.W. [*Ransomes, Westminster.*]
1888. Rapley, Frederick Harvey, Messrs. J. E. and M. Clark and Co., Dashwood House, London, E.C.
1883. Rathbone, Edgar Philip, Mining Engineer, 2 Great George Street, Westminster, S.W. [*Basera, London.* 3117.]
1867. Ratliffe, George, 81 Cannon Street Buildings, 139 Cannon Street, London, E.C.
1862. Ravenhill, John R., Delaford, Iver, near Uxbridge.
1872. Rawlins, John, Manager, Metropolitan Railway-Carriage and Wagon Works, Saltley, Birmingham. [*Metro, Birmingham.*]
1878. Rawlinson, Sir Robert, K.C.B., Lancaster Lodge, 11 Boltons, West Brompton, London, S.W.
1883. Reader, Reuben, Phœnix Works, Cremorne Street, Nottingham.

1887. Readhead, Robert, Messrs. John Readhead and Co., West Docks, South Shields.

1882. Reay, Thomas Purvis, Messrs. Kitson and Co., Airedale Foundry, Leeds.

1881. Redpath, Francis Robert, Canada Sugar Refinery, Montreal, Canada. [*Redpath, Montreal.*]

1883. Reed, Alexander Henry, 90 Cannon Street, London, E.C. [*Wagon, London.*]

1870. Reed, Sir Edward James, K.C.B., M.P., F.R.S., Broadway Chambers, Westminster, S.W. [*Carnage, London.*]

1884. Rees, William Thomas, Mining Engineer, Gadlys Cottage, Aberdare.

1883. Reid, James, Messrs. Neilson and Co., Hyde Park Locomotive Works, Glasgow.

1859. Rennie, George Banks, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.; and 20 Lowndes Street, Lowndes Square, London, S.W.

1879. Rennie, John Keith, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.

1881. Rennoldson, Joseph Middleton, Marine Engine Works, South Shields. [*Rennoldson, South Shields.* 11.]

1876. Restler, James William, Engineer, Southwark and Vauxhall Water Works, Sumner Street, Southwark, London, S.E.

1883. Reunert, Theodore, Kimberley, South Africa: (or care of Messrs. Findlay Durham and Brodie, 61 St. Mary Axe, London, E.C.)

1862. Reynolds, Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1879. Reynolds, George Bernard, Assistant Manager, Wardha Coal State Railway, Warora, Central Provinces, India; care of Messrs. Grindlay Groom and Co., Bombay, India; and 23 Longridge Road, Earl's Court, London, S.W.

1882. Rhodes, Vincent, Manager, Messrs. Hudson Brothers, Clyde Engineering Works, Granville, near Sydney, New South Wales: (or care of Mrs. E. A. Rhodes, 5 Ainger Terrace, St. Catherine's Road, Grantham.)

1866. Richards, Edward Windsor, Low Moor Iron Works, near Bradford.

1882. Richards, George, Messrs. George Richards and Co., Atlantic Works, Broadheath, near Manchester. [*Richards, Altrincham.*]

1856. Richards, Josiah, Pontypool Iron and Tinplate Works, Pontypool.

1884. Richards, Lewis, Dowlais Iron and Steel Works, Dowlais.

1863. Richardson, The Hon. Edward, C.M.G., Minister of Public Works, Christchurch, Canterbury, New Zealand.

1865. Richardson, John, Methley Park, near Leeds.

1873. Richardson, John, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1887. Richardson, Thomas, Jun., Messrs. T. Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1859. Richardson, William, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1884. Riches, Charles Hurry, Assistant Locomotive Superintendent, Taff Vale Railway, Cardiff.

1874. Riches, Tom Hurry, Locomotive Superintendent, Taff Vale Railway, Cardiff. [*Locomotive, Cardiff.*]

1873. Rickaby, Alfred Austin, Bloomfield Engine Works, Sunderland. [*Rickaby, Sunderland.*]

1879. Ridley, James Cartmell, Queen Street, Newcastle-on-Tyne.

1887. Riekie, John, District Locomotive Superintendent, North Western Railway, Hirokh, Beluchistan, India.

1874. Riley, James, General Manager, Steel Company of Scotland, 150 Hope Street, Glasgow.

1884. Ripper, William, Assistant Professor of Mechanical Engineering, The Technical School, St. George's Square, Sheffield.

1879. Rixom, Alfred John, 1 Gordon Villas, Park Road, Loughborough.

1887. Roberts, Thomas, Assistant Locomotive Engineer, Government Railways, Adelaide, South Australia.

1879. Roberts, Thomas Herbert, Mechanical Superintendent, Chicago and Grand Trunk Railway, Detroit, Michigan, United States.

1887. Roberts, William, 9 Victoria Chambers, 17 Victoria Street, Westminster, S.W.

1848. Robertson, Henry, Great Western Railway, Shrewsbury; and Palé, Corwen.

1879. Robertson, William, Messrs. Boyd and Co., Engineers and Shipbuilders, Shanghai, China: (or care of Herbert J. Stockton, 16 Philpot Lane, London, E.C.)

1883. Robins, Edward, Dominica, West Indies: (or care of Charles Robins, 3 Holmdale Road, Denington Park, West Hampstead, London, N.W.)

1874. Robinson, Henry, Professor of Surveying and Civil Engineering, King's College, Strand, London, W.C.; and 7 Westminster Chambers, 13 Victoria Street, Westminster, S.W.

1876. Robinson, James Salkeld, Messrs. Thomas Robinson and Son, Railway Works, Rochdale. [*Robinson, Rochdale.*]

1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow; and Westwood Hall, Leek, near Stoke-upon-Trent.

1886. Robinson, John, Barry Dock and Railways, Barry, near Cardiff.

1878. Robinson, John Frederick, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow.

1878. Robinson, Thomas Neild, Messrs. Thomas Robinson and Son, Railway Works, Rochdale. [*Robinson, Rochdale.*]

1866. Robson, Thomas, Mining Engineer, Lumley Thicks, Fence Houses.

1888. Rock, John William, Kent Street, Sydney, New South Wales.

1879. Rodger, William, care of Messrs. Ralli Brothers, Bombay: (or care of Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow.)

1884. Rodrigues, José Maria de Chermont, Rua de S. Pedro 54 sobrado, Rio de Janeiro, Brazil: (or care of Messrs. Jacob Walter and Co., Billiter Square Buildings, London, E.C.)

1872. Rofe, Henry, 8 Victoria Street, Westminster, S.W.

1885. Rogers, Henry John, Watford Iron Works, Watford. [*Engineer, Watford.*]

1871. Rollo, David, Messrs. David Rollo and Sons, Fulton Engine Works, 10 Fulton Street, Liverpool.

1881. Ross, William, Messrs. Ross and Walpole, North Wall Iron Works, Dublin. [*Iron, Dublin.* 311.]

1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Peterborough.

1878. Routh, William Pole, 25 Rua de S. Francisco, Oporto, Portugal: (or care of Cyril E. Routh, St. Michael's House, Cornhill, London, E.C.)

1888. Rowan, James, Messrs. David Rowan and Son, Elliot Street, Glasgow.

1878. Russell, The Hon. William, George Town, Demerara, British Guiana; and 65 Holland Park, London, W.

1867. Ruston, Joseph, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln; and 6 Onslow Gardens, South Kensington, London, S.W. [*Ruston, Lincoln.*]

1884. Rutherford, George, Manager, Wallsend Slipway and Engineering Works, Cardiff. [*Wall, Cardiff.*]

1877. Rutter, Edward, The Cedars, Richmond, Surrey.

1885. Ryan, John, D.Sc., Professor of Physics and Engineering, University College, Bristol.

1883. Ryder, George, Turner Bridge Iron Works, Tong, near Bolton. [*Ryder, Bolton.* 33A.]

1866. Ryland,[1] Frederick, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich.

1866. Sacré, Alfred Louis, 60 Queen Victoria Street, London, E.C. [*Sextant, London.* 1668.]

1859. Sacré, Charles, Consulting Engineer, Manchester Sheffield and Lincolnshire Railway, Manchester; 18 Fountain Street, Manchester; and Sunnyside, Victoria Park, Manchester.

1883. Sadoine, Baron Eugène, 57 Rue des Augustins, Liége, Belgium.

1864. Saïd, Colonel M., Pasha, Engineer, Turkish Service, Constantinople: (or care of J. C. Frank Lee, 9 Park Crescent, Portland Place, London, W.)

1859. Salt, George, Sir Titus Salt, Bart., Sons and Co., Saltaire, near Bradford; and Royal Thames Yacht Club, 7 Albemarle Street, London, W.

1887. Salter, Frank, Messrs. B. Donkin and Co., 55A Southwark Park Road, Bermondsey, London, S.E.

1874. Sampson, James Lyons, Messrs. David Hart and Co., North London Iron Works, Wenlock Road, City Road, London, N. [*Bascule, London.* 6699.]

1865. Samuelson, Sir Bernhard, Bart., M.P., F.R.S., Britannia Iron Works, Banbury; and 56 Prince's Gate, South Kensington, London, S.W.; and Lupton, Brixham, South Devon.

1881. Samuelson, Ernest, Messrs. Samuelson and Co., Britannia Iron Works, Banbury.

1881. Sanders, Henry Conrad, Messrs. H. G. Sanders and Son, Victoria Works, Victoria Gardens, Notting Hill Gate, London, W.; and Elm Lodge, Southall.

1871. Sanders, Richard David, Hillside House, Berkhamsted.

1886. Sandford, Horatio, Messrs. E. A. and H. Sandford, Thames Iron Works, Gravesend.

1881. Sandiford, Charles, Locomotive and Carriage Superintendent, North Western Railway, Lahore, Punjaub, India.

1874. Sauvée, Albert, 22 Parliament Street, Westminster, S.W. [*Sovez, London.* 3133.]

1880. Saxby, John, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W. [*Signalmen, London.*]; and Cold Harbour Lawn, Wivelsfield, near Burgess Hill, S.O., Sussex.

1869. Scarlett, James, Messrs. E. Green and Son, 14 St. Ann's Square, Manchester.

1886. Scholes, William Henry, Water Works Engineer, Oficina de las Obras de Salubridad de la Capital, 553 Calle Sinpacha, Buenos Aires, Argentine Republic: (or care of George Scholes, Orwell House, Upton Manor, Plaistow, London, E.)

1883. Schönheyder, William, 4 Rosebery Road, Brixton, London, S.W.

1880. Schram, Richard, 17A Great George Street, Westminster, S.W. [*Schram, London.*]

1886. Schurr, Albert Ebenezer, Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.; and Lyncot, Romford.

1885. Scorgie, James, Professor of Applied Mechanics, Civil Engineering College, Poona, India: (or care of Messrs. W. Watson and Co., 27 Leadenhall Street, London, E.C.)

1882. Scott, Charles Herbert, Bessemer Steel Works, Sheffield.

1875. Scott, Frederick Whitaker, Atlas Steel and Iron Wire Rope Works, Reddish, Stockport. [*Atlas, Reddish.*]

1881. Scott, George Innes, 9 Queen Street, Newcastle-on-Tyne.

1877. Scott, Irving M., Union Iron Works, San Francisco, California.

1881. Scott, James, Umlaas Wool-Scouring Works, Durban, Natal: (or care of Mr. Wallace, The Home Farm, Murthly, Perthshire.)

1886. Scott, James, Consett Iron Works, Consett, R.S.O., County Durham.

1885. Scott, Robert, Engineer, Messrs. Takata and Co., Tsukiji, Tokio, Japan; and 88 Bishopsgate Street Within, London, E.C.

1861. Scott, Walter Henry, Locomotive Superintendent, Great Southern Railway, Buenos Aires, Argentine Republic: (or care of H. Eaton, 75 Tulse Hill, London, S.W.)

1884. Scott-Moncrieff, William Dundas, 86 Newman Street, Oxford Street, London, W.

1868. Scriven, Charles, Whinfield Mount, Chapel Allerton, Leeds. [*Scriven, Leeds.*]

1882. Seabrook, Alfred William, Engineer Surveyor to the Port of Bombay, Port Office, Bombay.

1882. Seaton, Albert Edward, Earle's Shipbuilding and Engineering Works, Hull.

1864. Seddon, John, 98 Wallgate, Wigan.

1886. Seddon, Robert Barlow, Manager, Wigan Wagon Works, Wigan.

1882. Selfe, Norman, 141 Pitt Street, Sydney, New South Wales.

1884. Sellers, Coleman, E.D., Professor of Engineering, Stevens Institute, and Franklin Institute; 3301 Baring Street, Philadelphia, Pennsylvania, United States.

1888. Sellers, George, Holly Cottage, Wakefield.

1865. Sellers, William, Pennsylvania Avenue, Philadelphia, Pennsylvania, United States.

1881. Sennett, Richard, Admiralty, Whitehall, London, S.W.

1883. Shackleford, Arthur Lewis, General Manager, Britannia Railway-Carriage and Wagon Works, Saltley, Birmingham.

1884. Shackleford, William Copley, Manager, Lancaster Wagon Works, Lancaster.

1872. Shanks, Arthur, Messrs. A. Burn and Co., Howrah Iron Works, Howrah; and 7 Hastings Street, Calcutta.

1884. Shanks, William, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow. [*Shanks, Johnstone.*]

1881. Shanks, William Weallens, 18 Strand Road, Howrah, Bengal.

1881. Shapton, William, Sir William G. Armstrong Mitchell and Co., 8 Great George Street, Westminster, S.W.

1863. Sharp, Henry, Bolton Iron and Steel Works, Bolton.

1875. Sharp, Thomas Budworth, Managing Engineer, Muntz Metal Works, Birmingham.
1869. Sharrock, Samuel, Green Bank, Long Lane, Grassendale, Liverpool.
1882. Sharrock, Samuel Lord, Green Bank, Long Lane, Grassendale, Liverpool.
1879. Shaw, Henry Selby Hele, Professor of Engineering, University College, Liverpool.
1881. Shaw, Joshua, Messrs. John Shaw and Sons, Wellington Street Works, Salford, Manchester.
1881. Shaw, William, The Cast Steel Foundry, Middlesbrough.
1856. Shelley, Charles Percy Bysshe, 45 Parliament Street, Westminster, S.W.
1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.
1875. Sheppard, Herbert Gurney, Resident Engineer, Lake Aboukir Reclamation Works, near Alexandria, Egypt: (or 89 Westbourne Terrace, Hyde Park, London, W.)
1876. Shield, Henry, Messrs. Fawcett Preston and Co., Phœnix Foundry, 17 York Street, Liverpool.
1888. Shin, Tsuneta, 41 Kanetomicho, Koishikawa, Tokyo, Japan.
1885. Shuttleworth, Alfred, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln. [*Claytons, Lincoln.*]
1885. Shuttleworth, Major Frank, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln; and Old Warden Park, Biggleswade. [*Claytons, Lincoln.*]
1888. Siemens, Frederick, Dresden Glass Works, Dresden, Germany.
1888. Siemens, Dr. Werner, Messrs. Siemens and Halske, 94 Markgrafen Strasse, Berlin.
1871. Simon, Henry, 20 Mount Street, Manchester. [*Reform, Manchester.*]
1877. Simonds, William Turner (*Life Member*), Messrs. J. C. Simonds and Son, Oil Mills, Boston.
1876. Simpson, Arthur Telford, Engineer, Chelsea Water Works, 38 Parliament Street, Westminster, S.W.
1878. Simpson, James, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.
1885. Simpson, James Thomas, Executive Engineer, Public Works Department, Shwebo, Upper Burmah.
1882. Simpson, John Harwood, Manchester Ship Canal, 65 King Street, Manchester.
1847. Sinclair, Robert, care of Messrs. Sinclair Hamilton and Co., 17 St. Helen's Place, Bishopsgate Street, London, E.C. [*Sinclair, London.*]
1857. Sinclair, Robert Cooper, 3 Adelaide Place, London Bridge, London, E.C.
1881. Sisson, William, Messrs. Cox and Co., Falmouth Docks Engine and Shipbuilding Works, Falmouth. [*Sisson, Falmouth.*]

1885. Sivewright, George William, Messrs. Withy and Co., Middleton Ship Yard, West Hartlepool.

1872. Slater, Alfred, Gloucester Wagon Works, Gloucester.

1853. Slaughter, Edward, 25 Royal York Crescent, Clifton, Bristol.

1885. Slight, William Hooper, 44 Shaw Street, Hull: (or Woodborough Vicarage, Nottingham.)

1886. Small, James Miln, 4 The Sanctuary, Westminster, S.W.

1879. Smith, Allison Dalrymple, Assistant Locomotive Superintendent, Locomotive Workshops, Victorian Railways, Newport, Victoria.

1879. Smith, Charles Hubert, Engineer and Shipwright Surveyor to the Board of Trade, North Shields.

1866. Smith, Edward Fisher, 34 Avenue Road, Regent's Park, London, N.W.

1860. Smith, Henry, Messrs. Hill and Smith, Brierley Hill Iron Works, Brierley Hill; and Summerhill, Kingswinford, near Dudley. [*Fencing, Brierley Hill.*]

1881. Smith, Henry, Messrs. Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.

1860. Smith, Sir John, Parkfield, Duffield Road, Derby.

1876. Smith, John, Wintoun Terrace, Rochdale.

1883. Smith, John Bagnold, Newstead Colliery, near Nottingham.

1857. Smith, Josiah Timmis, Hæmatite Iron and Steel Works, Barrow-in-Furness; and Rhine Hill, Stratford-on-Avon.

1870. Smith, Michael Holroyd, Royal Insurance Buildings, Crossley Street, Halifax; and 18 Abingdon Street, Westminster, S.W. [*Outfall, London.*]

1886. Smith, Reginald Arthur, Messrs. Dorman and Smith, 24 Brazenose Street, Manchester.

1881. Smith, Robert Henry, Professor of Engineering, Mason Science College, Birmingham; and 10 St. Augustine's Road, Edgbaston, Birmingham.

1885. Smith, Thomas, Steam Crane Works, Old Foundry, Rodley, near Leeds. [*Tomsmith, Leeds.*]

1881. Smith, Wasteneys, 59 Sandhill, Newcastle-on-Tyne. [*Wasteneys Smith, Newcastle-on-Tyne.* 429.]

1863. Smith, William Ford, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester.

1887. Smith, William Mark, District Locomotive Carriage and Wagon Superintendent, Great Southern and Western Railway, Cork.

1882. Smyth, James Josiah, Messrs. James Smyth and Sons, Peasenhall, Suffolk.

1884. Smyth, William Stopford, Engineer, Alexandra Docks, Newport, Monmouthshire.

1883. Snelus, George James, F.R.S., West Cumberland Iron and Steel Works, Workington.

1886. Snowdon, Frederick Seaton, 29 Tasman Road, Clapham, London, S.W.

1885. Snowdon, John Armstrong, Stanners Closes Steel Works, Wolsingham, near Darlington.

1878. Sopwith, Thomas, Mining Engineer, 6 Great George Street, Westminster, S.W. [*Sopwith, London.* 3175.]

1887. Sorabji, Shapurji, Bombay Foundry and Engine Works, Khetwady, Bombay: (or care of Messrs. S. and E. Ransome and Co., 10 Essex Street, Strand, London, W.C.)

1884. Soulsby, James Charlton, 17 Mount Stuart Square, Cardiff.

1885. Southwell, Frederick Charles, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham.

1877. Soyres, Francis Johnstone de, Messrs. Bush and De Soyres, Bristol Iron Foundry, Bristol.

1887. Spence, William, Cork Street Foundry and Engineering Works, Dublin.

1887. Spencer, Alexander, 77 Cannon Street, London, E.C.

1878. Spencer, Alfred G., Messrs. George Spencer and Co., 77 Cannon Street, London, E.C.

1878. Spencer, George, Messrs. George Spencer and Co., 77 Cannon Street, London, E.C.

1877. Spencer, John, Globe Tube Works, Wednesbury [*Tubes, Wednesbury.*]; and 3 Queen Street Place, Cannon Street, London, E.C. [*Tubes, London.*]

1867. Spencer, John W., Newburn Steel Works, Newcastle-on-Tyne. [*Newburn, Newcastle-on-Tyne.*]

1885. Spencer, Mountford, Messrs. Luke and Spencer, Ardwick, Manchester; and The Meadows, Alderley Edge, near Manchester.

1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne. [*Newburn, Newcastle-on-Tyne.*]

1876. Spice, Robert Paulson, 21 Parliament Street, Westminster, S.W.

1885. Spooner, George Percival, Locomotive Superintendent, Bolan Railway, Hirokh, Beluchistan, India.

1883. Spooner, Henry John, 309 Regent Street, London, W.

1869. Stabler, James, 13 Effra Road, Brixton, London, S.W.

1877. Stanger, George Hurst, Queen's Chambers, North Street, Wolverhampton.

1875. Stanger, William Harry, Chemical Laboratory and Testing Works, Broadway, Westminster, S.W.

1888. Stanley, Harry Frank, Messrs. Pontifex and Wood, Farringdon Works, Shoe Lane, London, E.C.

1888. Stannah, Joseph, 20 Southwark Bridge Road, London, S.E.

1884. Stanton, Frederic Barry, Mansion House Chambers, 11 Queen Victoria Street, London, E.C.

1866. Stephens, John Classon, Messrs. Stephens and Co., Vulcan Iron Works, Sir John Rogerson's Quay, Dublin.

1874. Stephens, Michael, Locomotive Superintendent, Cape Government Railways, Cape Town, Cape of Good Hope.

1868. Stephenson, George Robert, 9 Victoria Chambers, 17 Victoria Street, Westminster, S.W. [*Precursor, London.*]

1879. Stephenson, Joseph Gurdon Leycester, 6 Drapers' Gardens, London, E.C. [*Fluvius, London.*]

1888. Stephenson-Peach, William John, Trent Fish Culture Co., Milton, Burton-on-Trent.

1876. Sterne, Louis, Messrs. L. Sterne and Co., Crown Iron Works, Glasgow [*Crown, Glasgow.*]; and 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W. [*Elsterne, London.* 3066.]

1887. Stevenson, David Alan, F.R.S.E., 84 George Street, Edinburgh.

1878. Stevenson, George Wilson, 38 Parliament Street, Westminster, S.W.

1877. Stewart, Alexander, Manager, Messrs. Thwaites Brothers, Vulcan Iron Works, Thornton Road, Bradford.

1887. Stewart, Andrew, 41 Oswald Street, Glasgow.

1878. Stewart, Duncan, Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow. [*Stewart, Glasgow.* 531.]

1851. Stewart, John, Blackwall Iron Works, Poplar, London, E. [*Steamships, London.*]

1885. Stewart-Hamilton, Patrick, care of Rev. Alexander Hamilton, D.D., The Manse, Brighton.

1888. Stiff, William Charles, Credenda Seamless Steel-Tube Works, Ledsam Street, Birmingham.

1880. Stirling, James, Locomotive Superintendent, South Eastern Railway, Ashford, Kent.

1885. Stirling, Matthew, Locomotive Superintendent, Hull Barnsley and West Riding Junction Railway and Dock Co., Hull.

1867. Stirling, Patrick, Locomotive Superintendent, Great Northern Railway, Doncaster.

1888. Stirling, Robert, North Eastern Railway, Locomotive Department, Gateshead.

1875. Stoker, Frederick William, Messrs. Easton and Anderson, Erith Iron Works, Erith, S.O., Kent.

1877. Stokes, Alfred Allen, Elmcote, Godalming.

1887. Stone, Frank Holmes, care of Messrs. Robinson and Co., Beach Street, Penang: (or care of L. H. Moorsom, 20 Cooper Street, Manchester.)

1877. Stothert, George Kelson, Steam Ship Works, Bristol.

888. Strachan, James, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Nottingham.

1888. Straker, Sidney, 240 Stanstead Road, Forest Hill, London, S.E.

1884. Stronge, Charles, Locomotive Department, Porto Alegre and New Hamburg Railway, São Leopoldo, Rio Grande do Sol, Brazil: (or 1 Albion Street, Hyde Park, London, W.)

1865. Stroudley, William, Locomotive Superintendent, London Brighton and South Coast Railway, Brighton; and Bosvigo, Preston Park, Brighton.

1873. Strype, William George, The Murrough, Wicklow [*Strype, Wicklow.*]; 1 College Street, Dublin; and Park Avenue, Sydney Parade, near Dublin.

1878. Stuart, James, M.P., Professor of Mechanism in Cambridge University, Trinity College, Cambridge.

1882. Sturgeon, John, 4 Burlington Chambers, New Street, Birmingham. [*Air, Birmingham.*]

1882. Sugden, Thomas, Chadderton Iron Works, Irk Vale, Chadderton, near Manchester.

1861. Sumner, William, 2 Brazenose Street, Manchester.

1875. Sutcliffe, Frederic John Ramsbottom, Engineer, Low Moor Iron Works, near Bradford.

1883. Sutton, Joseph Walker, 64 South Lambeth Road, London, S.W.

1880. Sutton, Thomas, Carriage and Wagon Superintendent, Furness Railway, Barrow-in-Furness.

1887. Suverkrop, John Peter, 4A St. Andrew Square, Edinburgh.

1882. Swaine, John, Messrs. Wright Butler and Co., Panteg Steel Works, near Newport, Monmouthshire.

1884. Swan, Joseph Wilson, 57 Holborn Viaduct, London, E.C.; and Lauriston, Bromley, Kent.

1882. Swinburne, William, Messrs. Henry Watson and Son, High Bridge Works, Newcastle-on-Tyne.

1864. Swindell, James Swindell Evers, Clent House, Stourbridge.

1878. Taite, John Charles, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C. [1618.]

1882. Tandy, John O'Brien, London and North Western Railway, Locomotive Department, Crewe; and 4 Wellington Villas, Wellington Square, Crewe.

1875. Tangye, George, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham. [*Tangyes, Birmingham.*]

1861. Tangye, James, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham; and Aviary Cottage, Illogan, near Redruth.

1879. Tartt, William, Maythorn, Blindley Heath, Godstone, near Red Hill.

1876. Taunton, Richard Hobbs, Messrs. Taunton and Hayward, Star Tube Works, Heneage Street, Birmingham. [*Taunton, Birmingham.*]

1882. Tayler, Alexander James Wallis, 77 Victoria Road, Kilburn, London, N.W.

1874. Taylor, Arthur, Manager, Lahat Tin Mines, Perak, viâ Penang; and 6 Queen Street Place, Upper Thames Street, London, E.C.

1858. Taylor, James, Britannia Engine Works, Cleveland Street, Birkenhead. [*Britannia, Birkenhead.* 4045.]

1887. Taylor, James, Messrs. Buckley and Taylor, Castle Iron Works, Oldham.

1873. Taylor, John, Midland Foundry, Queen's Road, Nottingham.

1867. Taylor, Joseph, Corinthian Villa, Acock's Green, near Birmingham.

1875. Taylor, Joseph Samuel, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham. [*Derwent, Birmingham.*]

1874. Taylor, Percyvale, Messrs. Burthe and Taylor, 26 Rue de Caumartin, Paris.

1882. Taylor, Robert Henry, Regent House, Wilson Grove, Southsea, B.O., Portsmouth.

1882. Taylor, Thomas Albert Oakes, Messrs. Taylor Brothers and Co., Clarence Iron Works, Leeds.

1864. Tennant, Sir Charles, Bart. (*Life Member*), The Glen, Innerleithen, near Edinburgh.

1882. Terry, Stephen Harding, Local Government Board, Whitehall, London, S.W.

1877. Thom, William, Messrs. W. and J. Yates, Canal Foundry, Blackburn.

1867. Thomas, Joseph Lee, 2 Hanover Terrace, Ladbroke Square, Notting Hill, London, W.

1888. Thomas, Philip Alexander, Yaryan Evaporating Co., 39 Palmerston Buildings, Bishopsgate Street Within, London, E.C.

1864. Thomas, Thomas, 10 Richmond Road, Roath, Cardiff.

1874. Thomas, William Henry, 15 Parliament Street, Westminster, S.W.

1875. Thompson, John, Highfields Boiler Works, Ettingshall, near Wolverhampton.

1883. Thompson, Richard Charles, Messrs. Robert Thompson and Sons, Southwick Shipbuilding Yard, Sunderland.

1857. Thompson, Robert, Victoria Chambers, Wigan; and Standish, near Wigan.

1880. Thompson, Thomas William, Eastham Ferry Pier, near Birkenhead.

1887. Thompson, William Phillips, 6 Lord Street, Liverpool.

1875. Thomson, James McIntyre, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow. [*Engineering, Glasgow.*]

1868. Thomson, John, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow. [*Engineering, Glasgow.*]

1868. Thornewill, Robert, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.

1885. Thornley, George, Messrs. Buxton and Thornley, Waterloo Engineering Works, Burton-on-Trent.

1877. Thornton, Frederic William, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1882. Thornton, Hawthorn Robert, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1888. Thornton, Robert Samuel, West's Patent Press Co., Etawah, North Western Provinces, India.

1876. Thornycroft, John Isaac, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W. [*Thornycroft, London.*]

1882. Thow, William, Locomotive Superintendent, South Australian Railways, Adelaide, South Australia: (or care of Joseph Meilbek, 7 Westminster Chambers, 13 Victoria Street, Westminster, S.W.)

1884. Thwaites, Arthur Hirst, Messrs. Thwaites Brothers, Vulcan Iron Works, Bradford. [*Thwaites, Bradford.* 325.]

1887. Thwaites, Edward Hirst, Messrs. Thwaites Brothers, Vulcan Iron Works, Bradford.

1885. Tijou, William, 38 Orchard Road, Highgate, London, N.

1885. Timmermans, François, Managing Director, Société anonyme des Ateliers de la Meuse, Liége, Belgium.

1884. Timmis, Illius Augustus, 2 Great George Street, Westminster, S.W. [*Timmis, London.*]

1886. Tipping, Henry, 38 Croom's Hill, Greenwich, London, S.E.

1888. Todd, Robert Ernest, Mechanical Engineer, La Madrid, Ferro Carril National Central Norte, Argentine Republic: (or care of William H. Todd, County Buildings, Land of Green Ginger, Hull.)

1875. Tomkins, William Steele, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow; and 12 Victoria Street, Westminster, S.W.

1857. Tomlinson, Joseph, Jun., 64 Priory Road, West Hampstead, London, N.W.

1888. Topple, Charles James, Machinery Department, Royal Arsenal, Woolwich.

1883. Tower, Beauchamp, 19 Great George Street, Westminster, S.W.

1886. Towne, Henry Robinson, Yale and Towne Manufacturing Co., Stamford, Connecticut, United States.

1888. Travis, Henry, Machinery Department, Royal Arsenal, Woolwich.

1883. Trentham, William Henry, 6 Park Crescent, Manor Park Road, Willesden, London, N.W.

1876. Trevithick, Richard Francis, Locomotive and Carriage Superintendent, Japanese Government Railways, Kobe, Japan: (or care of Mrs. Mary Trevithick, The Cliff, Penzance.)

1886. Trew, James Bradford, High Street, Watford, Herts.

1887. Trier, Frank, Messrs. Brunton and Trier, 19 Great George Street, Westminster, S.W.

1873. Trow, Joseph, Messrs. William Trow and Sons, Union Foundry, Wednesbury; and Victoria House, Holyhead Road, Wednesbury.

1885. Trueman, Thomas Brynalyn, care of T. W. Woodgate, 420 Rivadavia, Buenos Aires, Argentine Republic: (or care of Thomas R. Trueman, 7 Cambridge Villas, Twickenham.)

1887. Turnbull, Alexander, Messrs. Alexander Turnbull and Co., St. Mungo Works, Brook Street, Glasgow.

1883. Turnbull, Charles Henry, Mersey Dock Estate, Dock Yard, Liverpool.

1885. Turnbull, John, Jun., 255 Bath Street, Glasgow. [*Turbine, Glasgow.*]

1866. Turner, Frederick, Messrs. E. R. and F. Turner, St. Peter's Iron Works, Ipswich. [*Gippeswyk, Ipswich.*]

1886. Turner, George Reynolds, Vulcan Iron Works, Langley Mill, near Nottingham; and 81 Highgate Road, London, N.W.

1887. Turner, Joshua Alfred Alexander, Superintendent and Chief Engineer, Government Steam Flour Mills, Poona, India.

1882. Turner, Thomas, New British Iron Works, Corngreaves, near Birmingham.

1886. Turner, Tom Newsum, Vulcan Iron Works, Langley Mill, near Nottingham.

1876. Turney, Sir John, Messrs. Turney Brothers, Trent Bridge Leather Works, Nottingham. [*Turney, Nottingham.*]

1882. Tweedy, John, Messrs. Wigham Richardson and Co., Newcastle-on-Tyne.

1856. Tyler, Sir Henry Whatley, K.C.B., M.P., Pymmes Park, Edmonton, Middlesex.

1877. Tylor, Joseph John, 2 Newgate Street, London, E.C.

1878. Tyson, Isaac Oliver, Ousegate Iron Works, Selby.

1878. Unwin, William Cawthorne, F.R.S., Professor of Engineering, City and Guilds of London Central Institution, Exhibition Road, London, S.W.; and 7 Palace Gate Mansions, Kensington, London, W.

1875. Urquhart, Thomas, Locomotive Superintendent, Grazi and Tsaritsin Railway, Borisoglebsk, Tamboff Government, Russia.

1880. Valon, William Andrew McIntosh, Engineer, Corporation Gas and Water Works, Ramsgate. [*Valon, Ramsgate.*]

1885. Vaughan, William Henry, Royal Iron Works, West Gorton, Manchester. [*Pulleys, Openshaw.*]

1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.; and Rothbury, Blackheath Park, London, S.E. [*Exemplar, London.*]

1865. Vickers, Albert, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1861. Vickers, Thomas Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1888. Voysey, Henry Wesley, 130 Maygrove Road, Brondesbury, London, N.W.

1883. Waddell, James, Superintending Engineer, Netherlands India Steam Navigation Co., Soerabaya, Java; and 13 Austin Friars, London, E.C.

1887. Waddell, John, 4A St. Andrew Square, Edinburgh; and 14 Victoria Street, Westminster, S.W.

1856. Waddington, John, 35 King William Street, London Bridge, London, E.C.

1879. Wadia, Nowrosjee Nesserwanjee, Manager, Manockjee Petit Manufacturing Co., Tardeo, Bombay: (or care of Messrs. Hick Hargreaves and Co., Soho Iron Works, Bolton.) [*Wadia, Tardeo, Bombay.*]

1875. Wailes, John William, Patent Shaft Works, Wednesbury.

1884. Wailes, Thomas Waters, General Manager, Mountstuart Dry Dock and Engineering Works, Cardiff. [*Mountstuart, Cardiff.*]

1888. Waister, William Henry, Assistant Locomotive Superintendent, Great Western Railway, Stafford Road Works, Wolverhampton.

1881. Wake, Henry Hay, Engineer to the River Wear Commission, Sunderland.

1882. Wakefield, William, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Grand Canal Street, Dublin.

1873. Waldenström, Eric Hugo, 9 The Avenue, Lower Broughton Road, Manchester.

1867. Walker, Benjamin, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds. [*Tannett Walker, Leeds.*]

1877. Walker, David, Superintendent of Engineering Workshops, King's College, Strand, London, W.C.

1875. Walker, George, 95 Leadenhall Street, London, E.C.

1875. Walker, John Scarisbrick, Messrs. J. S. Walker and Brother, Pagefield Iron Works, Wigan; and 3 Alexandra Road, Southport. [*Pagefield, Wigan.*]

1884. Walker, Matthew, 22 Burns Street, Nottingham.

1886. Walker, Robert John, Church-Stile House, Shap, R.S.O., Westmoreland.

1884. Walker, Sydney Ferris, 195 Severn Road, Cardiff [*Dynamo, Cardiff.*]; and Hunter's Forge, New Bridge Street, Newcastle-on-Tyne. [*Dynamo, Newcastle-on-Tyne.*]

1876. Walker, Thomas Ferdinand, Ship's Log Manufacturer, 58 Oxford Street, Birmingham.

1878. Walker, William, Kaliemaas, Alleyne Park, West Dulwich, London, S.E. [*Bromo, London.*]

1863. Walker, William Hugill, Messrs. Walker Eaton and Co., Wicker Iron Works, Sheffield.

1878. Walker, Zaccheus, Jun., Fox Hollies Hall, near Birmingham.

1881. Walkinshaw, Frank, Yokohama Water Works, Yokohama, Japan: (or care of W. Walkinshaw, Hartley Grange, Winchfield.)

1884. Wallace, John, Backworth Collieries, near Newcastle-on-Tyne.

1884. Wallau, Frederick Peter, Messrs. Harland and Wolff, Belfast.

1868. Wallis, Herbert, Mechanical Superintendent, Grand Trunk Railway, Montreal, Canada.

1865. Walpole, Thomas, Messrs. Ross and Walpole, North Wall Iron Works, Dublin. [*Iron, Dublin.* 311.]

1877. Walton, James, 28 Maryon Road, Charlton.

1881. Warburton, John Seaton, 49 New Road, Grays, S.O., Essex; and 19 Stanwick Road, West Kensington, London, W.

1882. Ward, Thomas Henry, 58 Leopold Street, Loughborough.

1876. Ward, William Meese, Limerick Foundry, Great Bridge, Tipton.

1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Handsworth, near Birmingham. [*Bolts, Birmingham.*]

1856. Wardle, Charles Wetherell, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds. [*Manning, Leeds.*]

1882. Wardle, Edwin, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds.

1881. Warham, Richard Landor, 78 Warner Street, Derby.

1885. Warren, Henry John, Jun., Box 86, Wit Waters Randt, Johannesburg, Transvaal, South Africa: (or Hayle, Cornwall.)

1885. Warren, William, care of Messrs. Lopez and Co., Payta, Peru: (or care of Walter Ross, Hill Top, Blythe Hill, Catford, London, S.E.)

1882. Warsop, Henry, Clarendon Hotel, Nottingham.

1858. Waterhouse, Thomas (*Life Member*), Claremont Place, Sheffield.

1881. Watkins, Alfred, 2 Westcombe Park Road, Blackheath, London, S.E.

1862. Watkins, Richard, 94 Maida Vale, London, W.

1882. Watson, Henry Burnett, Messrs. Henry Watson and Son, High Bridge Works, Newcastle-on-Tyne. [*Watsons, Newcastle-on-Tyne.* 439.]

1879. Watson, William Renny, Messrs. Mirrlees Tait and Watson, Engineers, Glasgow.

1877. Watts, John, Broad Weir Engine Works, Bristol.

1877. Waugh, John, Chief Engineer, Yorkshire Boiler Insurance and Steam Users' Co., Sunbridge Chambers, Bradford. [*Boiler, Bradford.* 72.]

1886. Weatherburn, Robert, Locomotive Manager, Midland Railway Works, Kentish Town, London, N.W.

1878. Weatherhead, Patrick Lambert, Hotel Quatro Naciones, Seville, Spain: (or care of W. Weatherhead, Castlegate, Berwick-on-Tweed.)

1884. Webb, Richard George, Ashbury Railway-Carriage Works, Openshaw, Manchester.

1887. Webster, William, care of Messrs. Harris and Co., Samarang, Java.

1883. Weck, Friedrich, Town Hall Chambers, 86 New Street, Birmingham.

1888. Wellman, Samuel T., Otis Iron and Steel Works, Cleveland, Ohio, United States.

1862. Wells, Charles, Moxley Iron and Steel Works, near Bilston.

1882. West, Charles Dickinson, Professor of Mechanical Engineering, Imperial College of Engineering, Tokio, Japan.

1876. West, Henry Hartley, Naval Architect and Engineer, 14 Castle Street, Liverpool.

1874. West, Nicholas James, 36 Upper Park Road, Hampstead, London, N.W.

1877. Western, Charles Robert, Broadway Chambers, Westminster, S.W. [*Donbowes, London.* 3199.]

1877. Western, Maximilian Richard, care of Bombay Burmah Trading Corporation, Bangkok, Siam: (or care of Messrs. Wallace Brothers, 8 Austin Friars, London, E.C.)

1862. Westmacott, Percy Graham Buchanan, Sir W. G. Armstrong Mitchell and Co., Elswick Engine Works, Newcastle-on-Tyne; and Benwell Hill, Newcastle-on-Tyne.

1880. Westmoreland, John William Hudson, Lecturer on Engineering University College, Nottingham.

1867. Weston, Thomas Aldridge, Yale and Towne Manufacturing Co., 62 Reade Street, New York: (or care of J. C. Mewburn, 169 Fleet Street, London, E.C.)

1880. Westwood, Joseph, Napier Yard, Millwall, London, E. [*Westwood, London.* 5065.]

1888. Weyman, James Edwardes, Messrs. Weyman and Johnson, Church Acre Iron Works, Guildford.

1883. Wharton, Henry E., Engineering Manager, Basford Gas Works, Nottingham.

1881. Wharton, William Augustus, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Nottingham; and 3 Maples Street, Bentinck Road, Nottingham.

1884. Whieldon, John Henry, Campanhia do Beberibe, Rua Imperador, Pernambuco, Brazil: (or care of Ernest W. Whieldon, 42 Worlingham Road, East Dulwich, London, S.E.)

1882. White, Alfred Edward, Borough Engineer's Office, Town Hall, Hull.

1887. White, Alfred George, Assistant Engineer, Rio Tinto Railway, Huelva, Spain.

1874. White, Henry Watkins, 23 Leadenhall Street, London, E.C.; and 122 Lavender Hill, London, S.W.

1888. White, William Henry, F.R.S., Assistant Controller and Director of Naval Construction, Admiralty, Whitehall, London, S.W.

F 2

1885. Whitehead, James George, Mechanical Engineer, care of Enrique Swayne, 156 Calle Carabaya, Lima, Peru.

1876. Whiteley, William, Messrs. William Whiteley and Sons, Prospect Iron Works, Lockwood, Huddersfield.

1865. Whitley, Joseph, Railway Works, Hunslet Road, Leeds. [*Torpedo, Leeds.*]

1869. Whittem, Thomas Sibley, Wyken Colliery, Coventry.

1888. Whittle, John, Union Railway Wagon Works, Chorley.

1878. Whytehead, Hugh Edward, North Staffordshire Tramways, Stoke-on-Trent.

1878. Wicks, Henry, Superintendent, Messrs. Burn and Co., Howrah Iron Works, Howrah, Bengal, India: (or care of Dr. Wicks, South View House, West Parade, Newcastle-on-Tyne.)

1868. Wicksteed, Joseph Hartley, Messrs. Joshua Buckton and Co., Well House Foundry, Meadow Road, Leeds.

1878. Widmark, Harald Wilhelm, Helsingborgs Mekaniska Verkstad, Helsingborg, Sweden.

1881. Wigzell, Eustace Ernest, Billiter House, Billiter Street, London, E.C. [*Wigzell, London.* 1844.]

1882. Wilder, John, Yield Hall Foundry, Reading.

1886. Wildridge, John, Consulting Engineer and Marine Superintendent, Eastern and Australian Steamship Co., 34 Leadenhall Street, London, E.C.; and care of Messrs. Gibbs Bright and Co., Pitt Street, Sydney, New South Wales.

1888. Willans, Peter William, Messrs. Willans and Robinson, Ferry Works, Thames Ditton, Surrey. [*Willans, Thamesditton.*]

1885. Willcox, Francis William, 45 West Sunniside, Sunderland.

1883. Williams, Edward Leader, Engineer, Manchester Ship Canal Co., Manchester. [*Leader, Manchester.* 688.]

1884. Williams, John Begby, Messrs. William Gray and Co., Central Marine Engineering Works, West Hartlepool.

1884. Williams, John Rhys, Rhymney Iron Works, Rhymney, R.S.O., Monmouthshire.

1885. Williams, Nicholas Thomas, Barcellos Gold Mines, Taquarembosinho, Dom Pedrito, Rio Grande do Sul, Brazil: (or care of the Barcellos Gold Mining Co., 3 Tokenhouse Buildings, King's Arms Yard, London, E.C.)

1847. Williams, Richard, Brunswick House, Wednesbury.

1881. Williams, William Freke Maxwell, 35 Queen Victoria Street, London, E.C.

1873. Williams, William Lawrence, 16 Victoria Street, Westminster, S.W. [*Snowdon, London.*]

1883. Williamson, Richard, Messrs. Richard Williamson and Son, Iron Shipbuilding Yard, Workington.

1870. Willman, Charles, 26 Albert Road, Middlesbrough.

1884. Willock, Capt. Harry Borlase, R.E., War Office, Whitehall, London, S.W.

1878. Wilson, Alexander, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.

1882. Wilson, Alexander Basil, Holywood, Belfast. [*Wilson, Holywood.* 201.]

1872. Wilson, Alfred, Gas Furnace Engineer, Stafford. [*Wilson, Stafford.*]

1867. Wilson, Henry, Phœnix Brass Works, Stockton-on-Tees.

1884. Wilson, James, Chief Engineer of the Daira Sanieh, Egypt; Cairo, Egypt.

1881. Wilson, John, Engineer, Great Eastern Railway, Liverpool Street Station, London, E.C. [*Wilson, Eastern, London.*]

1863. Wilson, John Charles, 24 Lincoln's Inn Fields, London, W.C. [*Palacol, London.*]

1879. Wilson, Joseph William, Principal of School of Practical Engineering, Crystal Palace, Sydenham, London, S.E.

1880. Wilson, Robert, 10 St. Bride Street, London, E.C.; and 7 St. Andrew's Place, Regent's Park, London, N.W.

1883. Wilson, Robert, Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester.

1884. Wilson, Thomas, Superintendent, General Steam Navigation Company's Works, Deptford, London, S.E.

1873. Wilson, Thomas Sipling, British Vice-Consul, Brettesnœs, Lofoten Islands, Norway; and Messrs. Holroyd Horsfield and Wilson, Larchfield Foundry, Leeds: (or care of Messrs. James Bischoff and Sons, 10 St. Helen's Place, London, E.C.)

1888. Wilson, Walter Henry, Messrs. Harland and Wolff, Belfast.

1881. Wilson, Wesley William, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin.

1886. Windsor, Edwin Wells, 1 Rue du Hameau des Brouettes, Rouen, France.

1887. Winmill, George, Locomotive and Carriage Superintendent, Oudh and Rohilkund Railway, Lucknow, India; and Hare Street, Romford.

1872. Winstanley, Robert, Mining Engineer, 28 Deansgate, Manchester.

1872. Wise, William Lloyd, 46 Lincoln's Inn Fields, London, W.C. [*Lloyd Wise, London.* 2766.]

1871. Withy, Edward, Avon Villa, Parnell, Auckland, New Zealand.

1884. Withy, Henry, Messrs. Withy and Co., Middleton Ship Yard, West Hartlepool. [*Withy, West Hartlepool.* 4.]

1878. Wolfe, John Edward, General Manager, Alagoas Railway, Maceio, Brazil: (or care of Rev. Prebendary Wolfe, Arthington, Torquay.)

1878. Wolfenden, Richard, 11 Grafton Street, Moss Side, Manchester.

1878. Wolfenden, Robert, Revenue Cutter "Ling Fêng," care of Commissioner of Customs, Amoy, China; and 11 Grafton Street, Moss Side, Manchester.

1888. Wolff, Gustav William, Messrs. Harland and Wolff, Belfast.

1886. Wolff, Henri Michel, Hafna Lead Mining and Smelting Works, Llanrwst, R.S.O., Denbighshire.

1881. Wood, Edward Malcolm, 2 Westminster Chambers, 3 Victoria Street, Westminster, S.W.

1887. Wood, Henry, Messrs. J. and E. Wood, Victoria Foundry, Bolton.

1880. Wood, John Mackworth, Engineer's Department, New River Water Works, Clerkenwell, London, E.C.

1868. Wood, Lindsay, Mining Engineer, Southhill, near Chester-le-Street.

1885. Wood, Robert Henry, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds; and 15 Bainbrigge Road, Headingley, Leeds.

1884. Wood, Sidney Prescott, care of H. W. Little, Messrs. McKenzie and Holland, Vulcan Iron Works, Worcester.

1882. Woodall, Corbet, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1888. Woodford, Ethelbert George, State Engineer of Mines, Pretoria, South African Republic, Transvaal.

1884. Woodward, William, Engineer and Manager, Corporation Gas Works, Bury, Lancashire. [*Woodward, Bury.*]

1885. Wootton, Albert, Falcon Engine and Car Works, Loughborough.

1887. Worger, Douglas Fitzgerald, Assistant Engineer, Southwark and Vauxhall Water Works, 68 Sumner Street, Southwark, London, S.E.

1874. Worsdell, Thomas William, Locomotive Superintendent, North Eastern Railway, Gateshead. [*Locomotive, Gateshead.*]

1884. Worssam, Charles Smith, 35 Queen Victoria Street, London, E.C.

1877. Worssam, Henry John, Messrs. G. J. Worssam and Son, Wenlock Road, City Road, London, N. [*Massrow, London.* 6656.]

1886. Worthington, Charles Campbell, Messrs. Henry R. Worthington, Hydraulic Works, 145 Broadway, New York, United States: (or care of the Worthington Pumping Engine Co., 153 Queen Victoria Street, London, E.C.)

1888. Worthington, Edgar, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1860. Worthington, Samuel Barton, Consulting Engineer, 33 Princess Street, Manchester; and 12 York Place, Oxford Road, Manchester.

1866. Wren, Henry, Messrs. Henry Wren and Co., London Road Iron Works, Manchester. [*Henry Wren, Manchester.*]

1881. Wrench, John Mervyn, District Engineer, Indian Midland Railway, Jhansi, N.W. Provinces, India.

1881. Wright, Benjamin Frederick, Locomotive and Carriage Superintendent, Japanese Government Railways, Kobe, Japan: (or care of the Hong Kong and Shanghai Bank, 31 Lombard Street, London, E.C.)

1876. Wright, James, Messrs. Ashmore Benson Pease and Co., Stockton-on-Tees. [*Wright, Gasholder, Stockton.* 12.]

1867. Wright, John Roper, Messrs. Wright Butler and Co., Elba Steel Works, Gower Road, near Swansea.

1859. Wright, Joseph, Metropolitan Railway - Carriage and Wagon Co., Saltley Works, Birmingham; and 85 Gracechurch Street, London, E.C.

1860. Wright, Joseph, 16 Great George Street, Westminster, S.W.; and Lawnswood, Alexandra Road, Upper Norwood, London, S.E.

1878. Wright, William Barton, 148 Cromwell Road, South Kensington, London, S.W.

1871. Wrightson, Thomas, Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.

1886. Wylie, James, 28 Sycamore Road, Handsworth, R.O., Birmingham.

1865. Wyllie, Andrew, 1 Leicester Street, Southport.

1883. Wynne-Edwards, Thomas Alured, Agricultural Engineering Works, Denbigh. [*Foundry, Denbigh.*]

1877. Wyvill, Frederic Christopher, 19 East Parade, Leeds.

1878. Yates, Henry, Brantford, Ontario, Canada.

1882. Yates, Herbert Rushton, Assistant Engineer, Michigan Air Line Railway Extension, Pontiac, Michigan, United States: (or care of Henry Yates, Brantford, Ontario, Canada.)

1881. Yates, Louis Edmund Hasselts, District Locomotive Superintendent, Eastern Bengal State Railway, Sealdah, Calcutta: (or care of Rev. H. W. Yates, 98 Lansdowne Place, Brighton.)

1880. York, Francis Colin, Buenos Aires and Pacific Railway, Junin, Buenos Aires, Argentine Republic: (or care of Messrs. Samuel York Sons and Co., Snow Hill, Wolverhampton.)

1879. Young, George Scholey, Messrs. T. A. Young and Son, Orchard Place, Blackwall, London, E.

1874. Young, James, Managing Engineer, Lambton Colliery Works, Fence Houses.

1879. Young, James, Low Moor Iron Works, near Bradford.

1887. Young, William Andrew, Messrs. Hawthorns and Co., Leith Engine Works, Leith.

1881. Younger, Robert, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1885. Zimmer, George Friedrich, care of J. Harrison Carter, 82 Mark Lane, London, E.C.

ASSOCIATES.

1880. Allen, William Edgar, Imperial Steel Works, Savile Street, Sheffield.
1880. Bagshawe, Washington, Monk Bridge Iron Works, Leeds.
1881. Barcroft, Henry, Bessbrook Spinning Works, County Armagh, Ireland.
1886. Bennison, William Clyburn, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.
1888. Brown, Harold, 2 Bond Court, Walbrook, London, E.C.
1888. Chrimes, Charles Edward, Messrs. Guest and Chrimes, Brass Works, Rotherham.
1887. Chubb, Edward George, Ironbridge Gas Works, Ironbridge, R.S.O., Shropshire.
1879. Clowes, Edward Arnott, Messrs. William Clowes and Sons, Duke Street, Stamford Street, London, S.E. [*Clowes, London.* 4558.]
1883. Fairholme, Capt. Charles, R.N., Heberlein Self-acting Railway Brake Co., 18 St. Dunstan's Hill, London, E.C.
1886. Fisher, Harry, Messrs. Burys and Co., Regent Steel Works, Sheffield.
1865. Gössell, Otto, 41 Moorgate Street, London, E.C.
1887. Hind, Enoch, Edgar Rise, Nottingham.
1884. Jackson, Edward, Midland Railway-Carriage and Wagon Works, Birmingham. [*Wagon, Birmingham.*]
1882. Jackson, William, Kingston Cotton Mill, Hull. [*Cotton, Hull.*]
1884. Livesey, Joseph Montague, Stourton Hall, Horncastle.
1865. Longsdon, Alfred, 9 New Broad Street, London, E.C.
1881. Lowood, John Grayson, Gannister Works, Attercliffe Road, Sheffield. [*Lowood, Sheffield.* 131.]
1883. Macilraith, James, 92 Regent Street, Glasgow. [*Macilraith, Glasgow.*]
1886. Mackenzie, Keith Ronald, Gillotts, Henley-on-Thames.
1868. Matthews, Thomas Bright, Messrs. Turton Brothers and Matthews, Phœnix Steel Works, Sheffield. [*Matthews, Sheffield.*]
1885. Moser, Charles Henry, Messrs. Moser and Sons, 178 High Street, Southwark, London, S.E. [*Moserson, London.* 4563.]
1887. Neville, Edward Hermann, Messrs. Julius G. Neville and Co., Oriel Chambers, Liverpool. [*Neville, Liverpool.* 3409.]
1886. Newton, Henry Edward, 6 Bream's Buildings, Chancery Lane, London, E.C.
1888. O'Sullivan, Alfred Timothy, Swansea.
1874. Paget, Berkeley, Low Moor Iron Office, 2 Laurence Pountney Hill, Cannon Street, London, E.C. [*Gryphon, London.*]

1886. Peacock, William J. P., Wells Street, Oxford Street, London, W.; and 41 St. James' Street, London, S.W.

1888. Peake, Robert Cecil, Stoke Lodge, Bletchley.

1887. Peech, Henry, Phœnix Bessemer Steel Works, near Sheffield.

1887. Peech, William Henry, Phœnix Bessemer Steel Works, near Sheffield.

1884. Phillips, Richard Morgan, 21 to 24 State Street, New York, United States. [*Sarita, New York.*]

1886. Raven, Henry Baldwin, Messrs. Hare and Co., 19 Surrey Street, Strand, London, W.C.

1882. Ridehalgh, George John Miller, Fell Foot, Newby Bridge, Ulverston.

1888. Rowell, John Henry, New Brewery, High Street, Gateshead.

1883. Sandham, Henry, Keeper, Science and Art Department, South Kensington Museum, London, S.W.

1875. Schofield, Christopher J., Vitriol and Alkali Works, Clayton, near Manchester.

1887. Scott, Walter, Victoria Chambers, Grainger Street West, Newcastle-on-Tyne. [*Contractor, Newcastle-on-Tyne.*]

1878. Stalbridge, The Right Hon. Lord, 12 Upper Brook Street, Grosvenor Square, London, W.

1886. Stumore, Frederick, 34 Leadenhall Street, London, E.C.

1884. Tilfourd, George, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1887. Tozer, Edward Sanderson, Phœnix Bessemer Steel Works, near Sheffield.

1888. Tucker, Thomas, Messrs. Isaac Tucker and Co., Turk's Head Brewery, Gateshead.

1869. Varley, John, Leeds Forge, Leeds.

1878. Watson, Joseph, Patent Office, 25 Southampton Buildings, London, W.C.

1883. Williamson, Robert S., Cannock and Rugeley Collieries, Hednesford, near Stafford.

GRADUATES.

1884. Adam, Frank, Sir W. G. Armstrong Mitchell and Co., Elswick, Newcastle-on-Tyne.

1885. Addis, Frederick Henry, Ajmere, India: (or care of Messrs. Grindlay and Co., 55 Parliament Street, London, S.W.)

1874. Allen, Frank, Messrs. Allen Alderson and Co., Gracechurch Street, Alexandria: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1882. Allgood, Robert Lancelot, Nunwick, Humshaugh, R.S.O., Northumberland.

1885. Amos, Ewart Charles, Mansion House Chambers, 11 Queen Victoria Street, London, E.C.; and The Sycamores, Beulah Hill, Upper Norwood, London, S.E.

1880. Anderson, Edward William, Messrs. Easton and Anderson, Erith Iron Works, Erith, S.O., Kent; and Roydon Lodge, Erith, S.O., Kent.

1882. Anderson, William, North Eastern Railway, Locomotive Department, Leeds.

1878. Appleby, Charles, Jun., 89 Cannon Street, London, E.C. [*Appleby's, London.* 1731.]

1883. Appleby, Percy Vavasseur, Messrs. Appleby Brothers, 89 Cannon Street, London, E.C.

1878. Armstrong, Joseph, Great Western Railway, Stafford Road Works, Wolverhampton.

1887. Ashby, Joseph Harrison, Ascot Heath, Berkshire.

1886. Atkey, Albert Reuben, Corporation Water Works, Nottingham.

1888. Bailey, Wilfred Daniel, India-rubber Gutta-percha and Telegraph Works, Casilla de Correo 1212, Buenos Aires, Argentine Republic.

1869. Bainbridge, Emerson, Nunnery Colliery Offices, New Haymarket, Sheffield.

1888. Barker, Eric Gordon, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1882. Barstow, Thomas Hulme, Railway Manager, Picton, Marlborough, New Zealand.

1888. Bell, Alexander Dirom, The Woll, Hawick.

1884. Bell, Robert Arthur, Burrakur Coal Co., Barakar, East Indian Railway, Bengal: (or care of Mrs. Bell, 30 Brompton Crescent, London, S.W.)

1880. Birkett, Herbert, care of Messrs. S. G. Sansinena and Co., 64 Peru, Buenos Aires, Argentine Republic; and 62 Green Street, Grosvenor Square, London, W.

1884. Bocquet, Harry, care of Arthur E. Shaw, Estacion Central, Buenos Aires, Argentine Republic: (or care of Joseph Harrison, Llanwye, Hampton Park, Hereford.)

1883. Booth, William Stanway, Messrs. Vivian and Sons, Hafod Foundry, Swansea.

1888. Boulding, Sidney, Messrs. William Green and Co., 21 Featherstone Street, London, E.C.

1886. Bourne, Thomas Johnstone, Southborough, Tunbridge Wells.

1888. Bradley, Arthur Ashworth, Old Buxton Lime Works, Buxton.

1887. Bremner, Bruce Laing, Rose Cottage, Vale Street, Denbigh: (or Streatham House, Canaan Lane, Edinburgh.)

1878. Brooke, Arthur, General Post Office, Auckland, New Zealand: (or care of Miss Helen Brooke, Sunnymead, The Rise, Sidcup, S.O., Kent.)

1886. Brown, Andrew, Messrs. T. Cosser and Co., McLeod Road Iron Works, Kurrachee, India: (or care of P. B. Brown, 77 Page Hall Road, Firth Park, Sheffield.)

1880. Buckle, William Harry Ray, Union Dock, Limehouse, London, E. [*Buckle, Fletchdock, London.* 5109.]

1886. Budenberg, Christian Frederick, 25 Demesne Road, Whalley Range Manchester.

1879. Burnet, Lindsay, Moore Park Boiler Works, Govan, near Glasgow. [*Burnet, Glasgow.* 1513.]

1887. Burnett, Arthur Sydney, 5 Ramsbottom Terrace, Horwich, near Bolton.

1884. Butler, Hugh Myddleton, Kirkstall Forge, near Leeds.

1886. Cairnes, Frederick Evelyn, 60 South Lambeth Road, London, S.W.

1883. Cairns, The Hon. Herbert John, care of Sir W. G. Armstrong Mitchell and Co., Elswick Engine Works, Newcastle-on-Tyne.

1886. Carver, Charles, Lace Machine Works, Alfred Street, Nottingham.

1885. Clarke, Leslie, 132 Westbourne Terrace, Hyde Park, London, W.

1883. Clench, Frederick McDakin, Bamgaon Tea Estate, Ballipara Post Office, Tezpore, Assam, Bengal.

1885. Clift, Leslie Everitt, Fernbank, Pittville, Cheltenham.

1885. Clifton, George Bellamy, Great Western Railway Electric Light Works, 150 Westbourne Terrace, Paddington, London, W.

1883. Clinkskill, Alfred Alphonse Rouff, 1 Holland Place, St. Vincent Street, Glasgow.

1886. Conyers, Sidney Ward, Existing Lines Office, Railway Department, Sydney, New South Wales.

1883. Cotton, Henry Streatfeild, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.; and 106 Ebury Street, London, S.W.

1888. Cox, Herbert Henry, Messrs. Cox and Co., Falmouth Docks Engine and Shipbuilding Works, Falmouth; and Hillside, Falmouth. [*Iron, Falmouth.*]

1887. Crosland, Delevante William, 22 Royal Crescent, Kensington, London, W.

1885. Crosta, Lorenzo William, Messrs. R. R. Newlove and Co., Crown Iron Works, Crocus Street, Nottingham; and 21 Mayfield Grove, Nottingham.

1876. Davis, Joseph, Lancashire and Yorkshire Railway, Engineer's Office, Manchester.

1875. Dawson, Edward, Messrs. Forster Brown and Rees, Guild Hall Chambers, Cardiff.

1884. Dixon, John, 115 York Place, Harpurhey, R. O., Manchester.

1868. Dugard, William Henry, Messrs. Dugard Brothers, Vulcan Rolling Mills, Bridge Street West, Summer Lane, Birmingham. [*Vulcan, Birmingham.*]

1885. Dutt, Jodoo Nauth, Chinsurah, Bengal, India.

1886. Duvall, Charles Anthony, The Lucigen Light Co., Page Street, Westminster, S.W.

1885. Edwards, Walter Cleeve, Assistant Engineer, Midland Railway, Greymouth, New Zealand.

1887. England, William Henry, 40 Matlock Terrace, Leeds.

1875. Ffolkes, Martin William Brown, 28 Davies Street, Grosvenor Square, London, W.

1885. Grant, John Macpherson, Sir W. G. Armstrong Mitchell and Co., Elswick Works, Newcastle-on-Tyne; and 63 Westmorland Road, Newcastle-on-Tyne.

1886. Grant, Percy, South Eastern Railway, Ashford, Kent; and Surrey Villa, Ashford, Kent.

1878. Greig, Alfred, Suffolk House, 5 Laurence Pountney Hill, London, E.C.

1886. Halsey, William Stirling, Jun., Egerton Woollen Mills, Dhariwal, Amritsar, Punjaub, India.

1887. Hanby, Wrey Albert Edward, Assistant Engineer, Public Works Department, Bengal, India: (or care of E. T. Hanby, 34 Bassein Park Road, Shepherd's Bush, London, W.)

1885. Head, Archibald Potter, 16 Rutland Street, Hampstead Road, London, N.W.

1882. Heath, Ashton Marler, care of Sir A. M. Rendel, 8 Great George Street, Westminster, S.W.

1877. Heaton, Arthur, Messrs. Heaton and Dugard, Metal and Wire Works, Shadwell Street, Birmingham. [*Heagard, Birmingham.*]

1874. Hedley, Thomas, 1 Huntly Road, Fairfield, Liverpool.

1883. Hill, John Kershaw, Engineer and Manager, West Surrey Water Works, High Street, Walton-on-Thames.

1887. Hogg, William, Craigmore, Blackrock, near Dublin.

1867. Holland, George, Mechanical Department, Grand Trunk Railway, Montreal, Canada.

1884. Holt, Follett, London and South Western Railway, Locomotive Department, Nine Elms, London, S.W.; and 3 Devonshire Terrace, Portland Place, London, W.

1886. Hosgood, John Howell, Locomotive Department, Taff Vale Railway, Cardiff.

1883. Howard, Harry James, Messrs. Colman's Mustard Mills, Carrow Works, Norwich.

1879. Howard, J. Harold, Britannia Iron Works, Bedford.

1883. Hulse, Joseph Whitworth, Messrs. Hulse and Co., Ordsal Tool Works, Regent Bridge, Salford, Manchester.

1887. Jones, Edward Ebden, 7 Combe Terrace, Westcombe Park, Blackheath, London, S.E.

1883. Keen, Francis Watkins, Patent Nut and Bolt Works, Smethwick, near Birmingham.

1884. King, Charles Philip, Royston House, Upper Richmond Road, Putney, London, S.W.

1885. Laidler, Thomas, Meldon House, Leopold Street, Burdett Road, London, E. [*Gravitation, London.*]

1883. Lander, Philip Vincent, Assistant Engineer, Argentine Great Western Railway, Mendoza, Argentine Republic: (or Lyndhurst, Hampton Wick, R.O., Kingston-on-Thames.)

1881. Lawson, James Ibbs, Resident Engineer, New Zealand Railways, Invercargill, Otago, New Zealand.

1888. Letchford, Joseph, care of Richard Speight, Chief Commissioner of Victorian Railways, Glenroy Park, Hampton Street, Middle Brighton, Melbourne, Victoria: (or care of James Letchford, 370 Wandsworth Road, London, S.W.)

1886. Lewis, William Thomas, Jun., Engineer's Office, Bute Docks, Cardiff; and Llwyn-yr-eos, Abercanaid, near Merthyr Tydfil.

1886. Lucy, William Theodore, Thornleigh, Woodstock Road, Oxford.

1881. Macdonald, Ranald Mackintosh, Messrs. Booth Macdonald and Co., Carlyle Engineering and Implement Works, Christchurch, New Zealand; and P.O. Box 89, Christchurch, New Zealand.

1883. Mackenzie, Thomas Brown, Messrs. J. Copeland and Co., Pulteney Street Engine Works, Glasgow; and 342 Duke Street, Glasgow.

1883. Malan, Ernest de Mérindol, Howden.

1868. Mappin, Frank, Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.

1883. Marrack, Philip, R.N., H.M.S. "Hibernia," Malta; and Burraton, Saltash, R.S.O., Cornwall.

1888. Marten, Hubert Bindon, 7 Endsleigh Terrace, Tavistock.

1882. Martindale, Warine Ben Hay, Southern Mahratta Railway, Haveri, Bombay Presidency, India; and 21 Kensington Gardens Square, London, W.

1886. Mattos, Alvaro Gomes de, 98 Rua da Sande, Rio de Janeiro, Brazil: (or care of Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.)

1887. May, Harold Milton, Hunslet Engine Works, Leeds.

1867. Mitchell, John, Swaithe Hall, Barnsley.

1868. Moor, William, Jun., Cross Lanes, Hetton-le-Hole, near Fence Houses.

1885. Mudie, Charles, Upper Assam Tea Co., Dibrugarh, Upper Assam, India: (or 52 Park Road, New Wandsworth, London, S.W.)

1878. Newall, John Walker, 62 Ogden Street, Ardwick, Manchester.

1882. Noble, Saxton William Armstrong, Sir W. G. Armstrong Mitchell and Co., Elswick Works, Newcastle-on-Tyne.

1883. O'Connor, John Frederick, 6 East Seventeenth Street, New York.

1883. Osborn, William Fawcett, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1881. Oswell, William St. John, 110 Cannon Street, London, E.C.

1883. Palchoudhuri, Bipradas, Moheshgunj Factory, Krishnugher, Bengal.

1887. Paterson, John Edward, Locomotive Department, New South Wales Government Railways, Redfern Works, Sydney, New South Wales.

1884. Philipson, William, Messrs. Atkinson and Philipson, 27 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 415.]

1888. Pilkington, Herbert, Tipton Green Furnaces, Tipton.

1887. Price-Williams, John Morgan, Engineer's Office, Great Northern Railway, 7 York Road, King's Cross, London, N.

1886. Price-Williams, Seymour William, 38 Parliament Street, Westminster, S.W.

1887. Pullen, William Wade Fitzherbert, 18 Crookham Road, Fulham, London, S.W.

1884. Reynolds, Thomas Blair, 5 Great George Street, Westminster, S.W.

1885. Ripley, Philip Edward, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich.

1887. Rogers, Horace Wyon, 43 Upper Thames Street, London, E.C.
1881. Rogers, Philip Powys, Assistant Engineer, Wardha Coal State Railway, Warora, Central Provinces, India: (or care of Messrs. Grindlay and Co., 55 Parliament Street, London, S.W.)
1884. Roux, Paul Louis, 54 Boulevard du Temple, Paris.
1888. Rümmele, Alfredo, 17 Via Principe Umberto, Milan, Italy.
1882. Sanchez, Juan Emilio, Talleres de Marina Nacionales, Tigre, Buenos Aires, Argentine Republic: (or care of Messrs. J. E. and M. Clark and Co., 9 New Broad Street, London, E.C.)
1881. Scott, Ernest, Close Works, Newcastle-on-Tyne. [*Esco, Newcastle-on-Tyne.* 432.]
1886. Silcock, Charles Whitbread, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.
1887. Simkins, Charles Wickens, The Lodge, Lowdham, near Nottingham.
1883. Simpson, Charles Liddell, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.
1883. Swale, Gerald, Ingfield Hall, Settle.
1887. Tabor, Edward, Henry, Great Eastern Railway, Stratford Works, London, E.
1885. Tangye, John Henry, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham.
1884. Taylor, Joseph, 19 Foskett Road, Fulham, London, S.W.
1884. Taylor, Maurice, Ateliers des Forges et Chantiers de la Méditerranée, Marseille, France.
1884. Templeton, Edwin Arthur Slade, 42 Boscombe Road, Shepherd's Bush, London, W.
1878. Waddington, John, Jun., 35 King William Street, London Bridge, London, E.C.
1888. Waddington, Samuel Sugden, 14 Ethel Street, Birmingham.
1882. Wailes, George Herbert, St. Andrews, Watford, Herts.
1885. Wakefield, William Marsden, care of Mark W. Carr, Government Railway, Pietermaritzburg, Natal, South Africa.
1884. Walker, Ralph Teasdale, Kaliemaas, Alleyne Park, West Dulwich, London, S.E.
1888. Waring, Henry, Messrs. J. Edmundson and Co., Stafford Works, 35 Capel Street, Dublin; and Elsinore, Harold's Cross Road, Dublin.
1886. Warren, Frank Llewellyn, 73 Breakspears Road, St. John's, London, S.E.
1886. Wesley, Joseph A., Clarke's Crank and Forge Works, Lincoln.
1883. Westmacott, Henry Armstrong, Sir W. G. Armstrong Mitchell and Co., Elswick Works, Newcastle-on-Tyne; and Benwell Hill, Newcastle-on-Tyne.

1880. Weymouth, Francis Marten, Messrs. Latimer Clark Muirhead and Co., 23 Regency Street, Westminster, S.W.; and 33 Alfred Road, Acton, London, W.

1888. Whichello, Richard, Messrs. Max Nothmann and Co., Rio de Janeiro, Brazil: (or 44 Trumpington Street, Cambridge.)

1879. Wood, Edward Walter Naylor, 7 Theresa Terrace, Hammersmith, London, W.

1882. Woollcombe, Reginald, District Locomotive Superintendent, Rajputana State Railway, Mhow, Central India; care of Messrs. King King and Co., Bombay.

1885. Wray, Charles Drinkwater, care of J. Harrison, 8 Wellfield Villas, Turnchapel, Plymouth: (or care of Lieut.-General Henry Wray, 101 Comeragh Road, West Kensington, London, S.W.)

1887. Wrench, John Henry Kirke, Broad Oaks Iron Works, Chesterfield.

1888. Yates, Edward, Watling Works, Stony Stratford.

1884. Yokoi, Saku, 110 Rue de Turenne, Paris.

THE INSTITUTION OF MECHANICAL ENGINEERS.

Memorandum of Association.

August 1878.

1st. The name of the Association is "The Institution of Mechanical Engineers."

2nd. The Registered Office of the Association will be situate in England.

3rd. The objects for which the Association is established are :—

(a.) To promote the science and practice of Mechanical Engineering and all branches of mechanical construction, and to give an impulse to inventions likely to be useful to the Members of the Institution and to the community at large.

(b.) To enable Mechanical Engineers to meet and to correspond, and to facilitate the interchange of ideas respecting improvements in the various branches of mechanical science, and the publication and communication of information on such subjects.

(c.) To acquire and dispose of property for the purposes aforesaid.

(d.) To do all other things incidental or conducive to the attainment of the above objects or any of them.

4th. The income and property of the Association, from whatever source derived, shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly, by way of dividend, bonus, or otherwise howsoever, by way of profit to the persons who at any time are or have been Members of the Association, or to any of them, or to any person claiming through any of them: Provided that nothing herein contained shall prevent the payment in good faith of remuneration to any officers or servants of the Association, or to any Member of the Association, or other person, in return for any services rendered to the Association, or prevent the giving of privileges to the Members of the Association in attending the meetings of the Association, or prevent the borrowing of money (under such powers as the Association and the Council thereof may possess) from any Member of the Association, at a rate of interest not greater than five per cent. per annum.

5th. The fourth paragraph of this Memorandum is a condition on which a licence is granted by the Board of Trade to the Association in pursuance of Section 23 of the Companies Act 1867. For the purpose of preventing any evasion of the terms of the said fourth paragraph, the Board of Trade may from time to time, on the application of any Member of the Association, impose further conditions, which shall be duly observed by the Association.

6th. If the Association act in contravention of the fourth paragraph of this Memorandum, or of any such further conditions, the liability of every Member of the Council shall be unlimited; and the liability of every Member of the Association who has received any such dividend, bonus, or other profit as aforesaid, shall likewise be unlimited.

7th. Every Member of the Association undertakes to contribute to the Assets of the Association in the event of the same being wound up during the time that he is a Member, or within one

year afterwards, for payment of the debts and liabilities of the Association contracted before the time at which he ceases to be a Member, and of the costs, charges, and expenses for winding up the same, and for the adjustment of the rights of the contributories amongst themselves, such amount as may be required not exceeding Five Shillings, or in case of his liability becoming unlimited such other amount as may be required in pursuance of the last preceding paragraph of this Memorandum.

8th. If upon the winding up or dissolution of the Association there remains, after the satisfaction of all its debts and liabilities, any property whatsoever, the same shall not be paid to or distributed among the Members of the Association, but shall be given or transferred to some other Institution or Institutions having objects similar to the objects of the Association, to be determined by the Members of the Association at or before the time of dissolution; or in default thereof, by such Judge of the High Court of Justice as may have or acquire jurisdiction in the matter.

Articles of Association.

August 1878.

INTRODUCTION.

Whereas an Association (hereinafter called "the existing Institution") called "The Institution of Mechanical Engineers" has long existed for objects similar to the objects expressed in the Memorandum of Association of the Association (hereinafter called "the Institution") to which these Articles apply, and the existing Institution consists of Members, Graduates, Associates, and Honorary Life Members, and is possessed of books, drawings, and property used for the objects aforesaid;

And whereas the Institution is formed for furthering and extending the objects of the existing Institution, by a registered Association, under the Companies Acts 1862 and 1867; and terms used in these Articles are intended to have the same respective meanings as they have when used in those Acts, and words implying the singular number are intended to include the plural number, and *vice versâ*;

Now therefore it is hereby agreed as follows:—

CONSTITUTION.

1. For the purpose of registration the number of Members of the Institution is unlimited.

MEMBERS.

2. The subscribers of the Memorandum of Association, and such other persons as shall be admitted in accordance with these Articles, and none others, shall be Members of the Institution, and be entered on the register as such.

3. Any person may become a Member of the Institution who, being a Member of the existing Institution, shall agree to transfer his membership of the existing Institution, and all rights and obligations incidental thereto, to the Institution, and to be registered as a Member of the Institution accordingly.

4. Any person may become a Member of the Institution who shall be qualified and elected as hereinafter mentioned, and shall agree to become such Member, and shall pay the entrance fee and first subscription accordingly.

5. The rights and privileges of every Member of the Institution shall be personal to himself, and shall not be transferable or transmissible by his own act or by operation of law.

QUALIFICATION AND ELECTION OF MEMBERS.

6. The qualification of Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

7. The election of Members shall be conducted as prescribed by the By-laws from time to time in force, as provided by the Articles.

GRADUATES, ASSOCIATES, AND HONORARY LIFE MEMBERS.

8. Any person may become a Graduate, Associate, or Honorary Life Member of the Institution, who, being already a Graduate, Associate, or Honorary Life Member of the existing Institution, shall agree to transfer his interest in the existing Institution, and all rights and obligations incidental thereto, to the Institution.

9. The Institution may admit such other persons as may be hereafter qualified and elected in that behalf as Graduates, Associates, and Honorary Life Members respectively of the Institution, and may confer upon them such privileges as shall be prescribed by the By-laws from time to time in force, as provided by the Articles: Provided that no Graduate, Associate, or Honorary Life Member shall be deemed to be a Member within the meaning of the Articles.

10. The qualification and mode of election of Graduates, Associates, and Honorary Life Members, shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

ENTRANCE FEES AND SUBSCRIPTIONS.

11. The Entrance Fees and Subscriptions of Members, Graduates, and Associates, shall be prescribed by the By-laws from time to time in force, as provided by the Articles: Provided that no Entrance Fee shall be payable by a Member, Graduate, or Associate of the existing Institution.

EXPULSION.

12. If any Member, Graduate, or Associate shall leave his subscription in arrear for two years, and shall fail to pay such arrears within three months after a written application has been sent to him by the Secretary, his name may be struck off the list of Members, Graduates, or Associates, as the case may be, by the Council, at any time afterwards, and he shall thereupon cease to

have any rights as a Member, Graduate, or Associate, but he shall nevertheless continue liable to pay the arrears of subscription due at the time of his name being so struck off: Provided always, that this regulation shall not be construed to compel the Council to remove any name if they shall be satisfied the same ought to be retained.

13. The Council may refuse to continue to receive the subscriptions of any person who shall have wilfully acted in contravention of the regulations of the Institution, or who shall in the opinion of the Council have been guilty of such conduct as shall have rendered him unfit to continue to belong to the Institution; and may remove his name from the list of Members, Graduates, or Associates (as the case may be), and such person shall thereupon cease to be a Member, Graduate, or Associate (as the case may be) of the Institution.

GENERAL MEETINGS.

14. The first General Meeting shall be held on such day, within four months of the registration of the Institution, as the Council shall determine. Subsequent General Meetings shall consist of the Ordinary Meetings, the Annual General Meeting, and of Special Meetings as hereinafter defined.

15. The Annual General Meeting shall take place in London in one of the first four months of every year. The Ordinary Meetings shall take place at such times and places as the Council shall determine.

16. A Special Meeting may be convened at any time by the Council, and shall be convened by them whenever a requisition signed by twenty Members of the Institution, specifying the object of the Meeting, is left with the Secretary. If for fourteen days after the delivery of such requisition a Meeting be not convened in accordance therewith, the Requisitionists or any twenty Members

of the Institution may convene a Special Meeting in accordance with the requisition. All Special Meetings shall be held in London.

17. Seven clear days' notice of every Meeting, specifying generally the nature of any special business to be transacted at any Meeting, shall be given to every Member of the Institution, and no other special business shall be transacted at such Meeting; but the non-receipt of such notice shall not invalidate the proceedings of such Meeting. No notice of the business to be transacted (other than such ballot lists as may be requisite in case of elections) shall be required in the absence of special business.

18. Special business shall include all business for transaction at a Special Meeting, and all business for transaction at every other Meeting, with the exception of the reading and confirmation of the Minutes of the previous Meeting, the election of Members, Graduates, and Associates, and the reading and discussion of communications as prescribed by the By-laws, or any regulations of the Council made in accordance with the By-laws.

PROCEEDINGS AT GENERAL MEETINGS.

19. Twenty Members shall constitute a quorum for the purpose of a Meeting other than a Special Meeting. Thirty Members shall constitute a quorum for the purposes of a Special Meeting.

20. If within thirty minutes after the time fixed for holding the Meeting a quorum is not present, the Meeting shall be dissolved, and all matters which might, if a quorum had been present, have been done at a Meeting (other than a Special Meeting) so dissolved, may forthwith be done on behalf of the Meeting by the Council.

21. The President shall be Chairman at every Meeting, and in his absence one of the Vice-Presidents; and in the absence of all Vice-Presidents a Member of Council shall take the chair; and if

no Member of Council be present and willing to take the chair, the Meeting shall elect a Chairman.

22. The decision of a General Meeting shall be ascertained by show of hands, unless, after the show of hands, a poll is forthwith demanded, and by a poll when a poll is thus demanded. The manner of taking a show of hands or a poll shall be in the discretion of the Chairman, and an entry in the Minutes, signed by the Chairman, shall be sufficient evidence of the decision of the General Meeting. Each Member shall have one vote and no more. In case of equality of votes the Chairman shall have a second or casting vote: Provided that this Article shall not interfere with the provisions of the By-laws as to election by ballot.

23. The acceptance or rejection of votes by the Chairman shall be conclusive for the purpose of the decision of the matter in respect of which the votes are tendered: Provided that the Chairman may review his decision at the same Meeting if any error be then pointed out to him.

BY-LAWS.

24. The By-laws set forth in the schedule to these Articles, and such altered and additional By-laws as shall be added or substituted as hereinafter mentioned, shall regulate all matters by the Articles left to be prescribed by the By-laws, and all matters which consistently with the Articles shall be made the subject of By-laws. Alterations in, and additions to, the By-laws, may be made only by resolution of the Members at an Annual General Meeting, after notice of the proposed alteration or addition announced at the previous Ordinary Meeting, and not otherwise.

COUNCIL.

25. The Council of the Institution shall be chosen from the Members only, and shall consist of one President, six Vice-Presidents, fifteen ordinary Members of Council, and of the Past-

Presidents; and the first Council (which shall include Past-Presidents of the existing Institution) shall be as follows:—

PRESIDENT.

John Robinson	Manchester.

PAST-PRESIDENTS.

Sir William G. Armstrong, C.B., D.C.L., LL.D., F.R.S.	Newcastle-on-Tyne.
Frederick J. Bramwell, F.R.S.	London.
Thomas Hawksley	London.
James Kennedy	Liverpool.
John Penn, F.R.S.	London.
John Ramsbottom	Manchester.
C. William Siemens, D.C.L., F.R.S.	London.
Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S.	Manchester.

VICE-PRESIDENTS.

I. Lowthian Bell, M.P., F.R.S.	Northallerton.
Charles Cochrane	Stourbridge.
Edward A. Cowper	London.
Charles P. Stewart	London.
Francis W. Webb	Crewe.
Percy G. B. Westmacott	Newcastle-on-Tyne.

COUNCIL.

Daniel Adamson	Manchester.
John Anderson, LL.D., F.R.S.E.	London.
Henry Bessemer	London.
Henry Chapman	London.
Edward Easton	London.
David Greig	Leeds.
Jeremiah Head	Middlesbrough.
Thomas R. Hetherington	Manchester.
Henry H. Laird	Birkenhead.
William Menelaus	Dowlais.
Arthur Paget	Loughborough.
John Penn, Jun.	London.
George B. Rennie	London.
William Richardson	Oldham.
John C. Wilson	Bristol.

26. The first Council shall continue in office till the Annual General Meeting in the year 1879. The President, two Vice-Presidents, and five Members of the Council (other than Past-Presidents), shall retire at each succeeding Annual General Meeting, but shall be eligible for re-election. The Vice-Presidents and Members of Council to retire each year shall, unless the Council agree amongst themselves, be chosen from those who have been longest in office, and in cases of equal seniority shall be determined by ballot.

27. The election of a President, Vice-Presidents, and Members of the Council, to supply the place of those retiring at the Annual General Meeting, shall be conducted in such manner as shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

28. The Council may supply any casual vacancy in the Council (including any casual vacancy in the office of President) which shall occur between one Annual General Meeting and another, and the President or Members of the Council so appointed by the Council shall retire at the succeeding Annual General Meeting. Vacancies not filled up at any such Meeting shall be deemed to be casual vacancies within the meaning of this Article.

OFFICERS.

29. The Treasurer, Secretary, and other employés of the Institution shall be appointed and removed in the manner prescribed by the By-laws from time to time in force, as provided by the Articles. Subject to the express provisions of the By-laws the officers and servants of the Institution shall be appointed and removed by the Council.

30. The powers and duties of the officers of the Institution shall (subject to any express provision in the By-laws) be determined by the Council.

POWERS AND PROCEDURE OF COUNCIL.

31. The Council may regulate their own procedure, and delegate any of their powers and discretions to any one or more of their body, and may determine their own quorum: if no other number is prescribed, three Members of Council shall form a quorum.

32. The Council shall acquire the property of the existing Institution, and shall manage the property, proceedings, and affairs of the Institution, in accordance with the By-laws from time to time in force.

33. The Treasurer may, with the consent of the Council, invest in the name of the Institution any moneys not immediately required for the purposes of the Institution in or upon any of the following investments (that is to say):—

(A.) The Public Funds, or Government Stocks of the United Kingdom, or of any Foreign or Colonial Government guaranteed by the Government of the United Kingdom.

(B.) Real or Leasehold Securities, or in the purchase of real or leasehold properties in Great Britain or Ireland.

(C.) Debentures, Debenture Stock, or Guaranteed or Preference Stock, of any Company incorporated by special Act of Parliament, the ordinary Shareholders whereof shall at the time of such investment be in actual receipt of half-yearly or yearly dividends.

(D.) Stocks, Shares, Debentures, or Debenture Stock of any Railway, Canal, or other Company, the undertaking whereof is leased to any Railway Company at a fixed or fixed minimum rent.

(E.) Stocks, Shares, or Debentures of any East Indian Railway or other Company, which shall receive a contribution from Her Majesty's East Indian Government of a fixed annual percentage on their capital, or be guaranteed a fixed annual dividend by the same Government.

(F.) The security of rates levied by any corporate body empowered to borrow money on the security of rates, where such borrowing has been duly authorised by Act of Parliament.

34. The Council may, with the authority of a resolution of the Members in General Meeting, borrow moneys for the purposes of the Institution on the security of the property of the Institution.

35. No act done by the Council, whether *ultra vires* or not, which shall receive the express or implied sanction of the Members of the Institution in General Meeting, shall be afterwards impeached by any Member of the Institution on any ground whatsoever, but shall be deemed to be an act of the Institution.

NOTICES.

36. A notice may be served by the Council of the Institution upon any Member, Graduate, Associate, or Honorary Life Member, either personally or by sending it through the post in a prepaid letter addressed to such Member, Graduate, Associate, or Honorary Life Member, at his registered place of abode.

37. Any notice, if served by post, shall be deemed to have been served at the time when the letter containing the same would be delivered in the ordinary course of the post, and in proving such service it shall be sufficient to prove that the letter containing the notice was properly addressed and put into the post office.

38. No Member, Graduate, Associate, or Honorary Life Member, not having a registered address within the United Kingdom shall be entitled to any notice; and all proceedings may be had and taken without notice to such Member in the same manner as if he had had due notice.

By-laws.

(Last Revision, January 1885.)

MEMBERSHIP.

1. Members, Graduates, Associates, and Honorary Life Members of the existing Institution, may, upon signing and forwarding to the Secretary of the Institution a claim according to Form D in the Appendix, become Members, Graduates, Associates, or Honorary Life Members respectively of the Institution without election or payment of entrance fees.

2. Candidates for admission as Members must be Engineers not under twenty-four years of age, who may be considered by the Council to be qualified for election.

3. Candidates for admission as Graduates must be Engineers holding subordinate situations and not under eighteen years of age; and they may afterwards be admitted as Members at the discretion of the Council.

4. Candidates for admission as Associates must be gentlemen not under twenty-four years of age, who from their scientific attainments or position in society may be considered eligible by the Council.

5. The Council shall have the power to nominate as Honorary Life Members gentlemen of eminent scientific acquirements, who in their opinion are eligible for that position.

6. The Members, Graduates, Associates, and Honorary Life Members shall have notice of and the privilege to attend all Meetings, but Members only shall be entitled to vote thereat.

ENTRANCE FEES AND SUBSCRIPTIONS.

7. An Entrance Fee of £2 shall be paid by each Member, except Members of the existing Institution, who shall pay no Entrance Fee, and Graduates admitted as Members, who shall pay an Entrance Fee of £1. Each Member shall pay an Annual Subscription of £3.

8. An Entrance Fee of £1 shall be paid by each Graduate, except Graduates of the existing Institution, who shall pay no Entrance Fee. Each Graduate shall pay an Annual Subscription of £2.

9. An Entrance Fee of £2 shall be paid by each Associate, except Associates of the existing Institution, who shall pay no Entrance Fee. Each Associate shall pay an Annual Subscription of £3.

10. All Subscriptions shall be payable in advance, and shall become due on the 1st day of January in each year; and the first Subscription of Members, Graduates, and Associates, shall date from the 1st day of January in the year of their election.

ELECTION OF MEMBERS, GRADUATES, AND ASSOCIATES.

11. A recommendation for admission according to Form A in the Appendix shall be forwarded to the Secretary, and by him be laid before the next Meeting of the Council. The recommendation must be signed by not less than five Members if the application be for admission as a Member or Associate, and by three Members if it be for a Graduate.

12. All Elections shall take place by ballot, three-fifths of the votes given being necessary for election.

13. All applications for admission shall be communicated by the Secretary to the Council for their approval previous to being

inserted in the ballot list for election, and the approved ballot list shall be signed by the President and forwarded to the Members. The ballot list shall specify the name, occupation, and address of the Candidates, and also by whom proposed and seconded. The lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

14. The Elections shall take place at the General Meetings only.

15. When the proposed Candidate is elected, the Secretary shall give him notice thereof according to Form B; but his name shall not be added to the list of Members, Graduates, or Associates of the Institution until he shall have paid his Entrance Fee and first Annual Subscription, and signed the Form C in the Appendix.

16. In case of non-election, no mention thereof shall be made in the Minutes, nor any notice given to the unsuccessful Candidate.

17. A Graduate or Associate desirous of being transferred to the class of Members shall forward to the Secretary a recommendation according to Form E in the Appendix, signed by not less than five Members, which shall be laid before the next meeting of Council for their approval. On their approval being given, the Secretary shall notify the same to the Candidate according to Form F if an Associate, and according to Form G if a Graduate; but his name shall not be added to the list of Members until he shall have signed the Form H, and, if a Graduate, shall have paid £1 additional entrance fee, and £1 additional subscription for the current year.

ELECTION OF PRESIDENT, VICE-PRESIDENTS, AND MEMBERS OF COUNCIL.

18. Candidates shall be put in nomination at the General Meeting preceding the Annual General Meeting, when the Council are to present a list of their retiring Members who offer themselves for re-election; any Member shall then be entitled to add to the

list of Candidates. The ballot list of the proposed names shall be forwarded to the Members. The ballot lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

APPOINTMENT AND DUTIES OF OFFICERS.

19. The Treasurer shall be a Banker, and shall hold the uninvested funds of the Institution, except the moneys in the hands of the Secretary for current expenses. He shall be appointed by the Members at a General or Special Meeting, and shall hold office at the pleasure of the Council.

20. The Secretary of the Institution shall be appointed as and when a vacancy occurs by the Members at a General or Special Meeting, and shall be removable by the Council upon six months' notice from any day. The Secretary shall give the same notice. The Secretary shall devote the whole of his time to the work of the Institution, and shall not engage in any other business or profession.

21. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all meetings of the Institution, and of the Council, and of Committees; to take minutes of the proceedings of such meetings; to read the minutes of the preceding meetings, and all communications that he may be ordered to read; to superintend the publication of such papers as the Council may direct; to have the charge of the library; to direct the collection of the subscriptions, and the preparation of the account of expenditure of the funds; and to present all accounts to the Council for inspection and approval. He shall also engage (subject to the approval of the Council) and be responsible for all persons employed under him, and set them their portions of work and duties. He shall conduct the ordinary business of the Institution, in accordance with the Articles and By-laws and the directions of the President and Council; and shall refer to the

President in any matters of difficulty or importance, requiring immediate decision.

MISCELLANEOUS.

22. All Papers shall be submitted to the Council for approval, and after their approval shall be read by the Secretary at the General Meetings, or by the Author with the consent of the Council.

23. All books, drawings, communications, &c., shall be accessible to the Members of the Institution at all reasonable times.

24. All communications to the Meetings shall be the property of the Institution, and be published only by the authority of the Council.

25. None of the property of the Institution—books, drawings, &c.—shall be taken out of the premises of the Institution without the consent of the Council.

26. All donations to the Institution shall be enumerated in the Annual Report of the Council presented to the Annual General Meeting.

27. The General Meetings shall be conducted as far as practicable in the following order:—

1st. The Chair to be taken at such hour as the Council may direct from time to time.

2nd. The Minutes of the previous Meeting to be read by the Secretary, and, after being approved as correct, to be signed by the Chairman.

3rd. The Ballot Lists, previously opened by the Council, to be presented to the Meeting, and the new Members, Graduates, and Associates elected to be announced.

4th. Papers approved by the Council to be read by the Secretary, or, with the consent of the Council, by the Author.

28. Each Member shall have the privilege of introducing one friend to any of the Meetings; but, during such portion of any meeting as may be devoted to any business connected with the management of the Institution, visitors shall be requested by the Chairman to withdraw, if any Member asks that this shall be done.

29. Every Member, Graduate, Associate, or Visitor, shall write his name and residence in a book to be kept for the purpose, on entering each Meeting.

30. The President shall ex officio be Member of all Committees of Council.

31. Seven clear days' notice at least shall be given of every meeting of the Council. Such notice shall specify generally the business to be transacted by the meeting. No business involving the expenditure of the funds of the Institution (except by way of payment of current salaries and accounts) shall be transacted at any Council meeting unless specified in the notice convening the meeting.

32. The Council shall present the yearly accounts to the Members at the Annual General Meeting, after being audited by a professional accountant, who shall be appointed annually by the Members at a General or a Special Meeting, at a remuneration to be then fixed by the Members.

33. In the case of Members, Associates, or Graduates, elected in the last three months of any year, the first subscription shall cover both the year of election and the succeeding year.

34. No Proceedings or Ballot Lists shall be sent to Members, Associates, or Graduates, who are in arrear with their subscriptions more than twelve months.

35. Any Member wishing to have a copy of the Papers sent to him for consideration beforehand can do so by sending in his name once in each year to the Secretary; and a copy of all Papers shall then be forwarded to him as early as possible prior to the date of the Meeting at which they are intended to be read.

36. At any Meeting of the Institution any Member shall be at liberty to re-open the discussion upon any Paper which has been read or discussed at the preceding Meeting; provided that he signifies his intention to the Secretary at least one month previously to the Meeting, and that the Council decide to include it in the notice of the Meeting as part of the business to be transacted.

APPENDIX.

FORM A.

Mr. being not under twenty-four years of age, and desirous of admission into the Institution of Mechanical Engineers, we the undersigned proposer and seconder from our personal knowledge, and we the three other signers from trustworthy information, propose and recommend him as a proper person to become a thereof.

Witness our hands, this day of

Members.

FORM B.

Sir,—I have to inform you that on the you were elected a of the Institution of Mechanical Engineers. In conformity with the rules, your election cannot be confirmed until the enclosed form be returned to me with your signature, and until your Entrance Fee and first Annual Subscription be paid, the amounts of which are and respectively. If these be not received within two months from the present date, the election will become void.

I am, Sir,

Your obedient servant,

Secretary.

FORM C.

I, the undersigned, being elected a of the Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they are now formed or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

FORM D.

As a of the Institution of Mechanical Engineers, I claim to become a of the Association incorporated under the same name.

Please register me as a

FORM E.

Mr.   being of the required age, and desirous of being transferred into the class of Members of the Institution, we, the undersigned, from our personal knowledge, recommend him as a proper person to become a Member of the Institution of Mechanical Engineers.

FORM F.

Sir,—I have to inform you that the Council have approved of your being transferred to the class of Members of the Institution of Mechanical Engineers. In conformity with the rules, your transference cannot be confirmed until the enclosed form be returned to me with your signature. If this be not received within two months from the present date, the transference will become void.

I am, Sir,

Your obedient servant,

Secretary.

FORM G.

Sir,—I have to inform you that the Council have approved of your being transferred to the class of Members of the Institution of Mechanical Engineers. In conformity with the rules, your transference cannot be confirmed until the enclosed form be returned to me with your signature, and until your additional Entrance Fee (£1) and additional Annual Subscription (£1) be paid for the current year. If these be not received within two months from the present date, the transference will become void.

I am, Sir,

Your obedient servant,

Secretary.

FORM H.

I, the undersigned, having been transferred to the class of Members of the Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they now exist, or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this   day of

Institution of Mechanical Engineers.

PROCEEDINGS.

February 1888.

The Forty-First Annual General Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Thursday, the 2nd of February 1888, at Half-past Seven o'clock p.m.; Edward H. Carbutt, Esq., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following thirty-one candidates were found to be duly elected:—

MEMBERS.

George Ashby,	Bombay.
William Henry Baraclough,	Birmingham.
Frederic Richard Boultbee,	British North Borneo.
Edward Bowen,	Brazil.
Arthur Chapman,	Calcutta.
Cursetjee Dadabhoy,	Bolton.
Henry George Ellery,	Leicester.
Joseph Evans,	Wolverhampton.
James Foster,	Samarang, Java.
Arthur Benjamin Frenzel,	London.
Henry Joseph Green,	Assam.
Alfred George Hamilton,	London.
Torazo Harada,	Osaka, Japan.

William Harker, ...	London.
Shun-ichi Hattori, ...	Nagoya, Japan.
Harold Homan, ...	Bury.
Piroshaw Bomanjee Jeejeebhoy, . .	Bolton.
David Allan Low, ...	London.
William Wilkie Melville, . .	Nottingham.
Frederick Harvey Rapley, . .	London.
Joseph Stannah, ...	London.
William John Stephenson-Peach, .	Burton-on-Trent.
Robert Stirling, ...	Gateshead.
Henry Travis, ...	Woolwich.
Henry Wesley Voysey, . . .	London.
Samuel T. Wellman, . . .	Ohio, U.S.
John Whittle, ...	Chorley.

GRADUATES.

Alexander Dirom Bell, . . .	Glasgow.
Sidney Boulding, ...	London.
Alfredo Rümmele, ...	Milan.
Henry Waring, ...	Dublin.

The following Annual Report of the Council was then read:—

ANNUAL REPORT OF THE COUNCIL.

1888.

In presenting to the Members the forty-first Annual Report of the Institution of Mechanical Engineers, the Council have the pleasure of stating that the number of names of all classes on the roll of the Institution at the end of last year was 1741, as compared with 1674 at the end of the previous year. During 1887 there were added to the register 130 names; against which the loss by deceases was 23 names, and by resignation or removal 40, leaving a net gain of 67.

The following transference of a Graduate to the class of Members has been made by the Council in 1887:—

HARRY ALLCARD, ... Sheffield.

The following seventeen Deceases of Members of the Institution have occurred during the past year:—

FRANCIS HENRY BEATTIE, ... Birmingham.
JOHN BROUNLIE (Graduate), ... Tientsin.
WILLIAM BARBER BUDDICOM, ... Mold.
WALTER SCOTT DAVY, ... Sheffield.
WILLIAM DENNY, F.R.S.E., ... Dumbarton.
EDWARD FLETCHER, ... Manchester.
EDWARD FORSTER, ... Spon Lane.
SAMUEL GODFREY, ... Middlesbrough.
THOMAS JOHN HAYNES, ... Gibraltar.
Major-General HENRY HYDE, R.E., ... London.
JOHN MAYLOR, ... Chester.
WILLIAM MCONIE, JUN., ... Glasgow.
THOMAS ROUTLEDGE, ... Sunderland.
ELI SPENCER, ... Oldham.
WILLIAM STABLEFORD, ... Birmingham.
JEAN LOUIS TRASENSTER (Honorary Member), . . Liége.
Sir JOSEPH WHITWORTH, Bart., ... Manchester.

Of these Mr. William Denny was a Member of Council from the year 1885. Although he had only attained his fortieth year, he had nevertheless achieved a high reputation, especially in connection with that branch of mechanical engineering which deals with naval architecture.

M. Trasenster, so well known as the Rector of the University of Liége, was nominated an Honorary Life Member of this Institution on the occasion of the Summer Meeting in Belgium in 1883.

Sir Joseph Whitworth, whose decease was announced at the last Annual General Meeting, had been a Member of the Institution from the commencement in 1847, and occupied the Presidential chair in the three years 1856, 1857, and 1866. He has left to the Institution a bequest of forty fully-paid £25 shares in "Sir Joseph Whitworth and Co.," which are accordingly included in the balance sheet for the year.

The following nineteen gentlemen have ceased to be Members of the Institution during the past year :—

Joseph Liddell Anderson,	London.
Gordon McDakin Clench (*Graduate*),	Lincoln.
William John Coe,	Liverpool.
Henry S. Cropper,	Nottingham.
Robert Francis Drury (*Associate*),	Sheffield.
Henry Houldsworth Grierson,	Manchester.
James Hart,	Slaughter, U.S.
Paul Nooncree Hasluck (*Associate*),	London.
Thomas Howard Hepworth,	Southport.
Walter Sandell Mappin,	London.
Robert Sydney Milles (*Graduate*),	Tasmania.
Cecil Brooke Palmer,	Bellevue, U.S.
Arthur Henry Wright Radcliffe,	Birmingham.
William David Rees,	Swansea.
John Alexander George Ross,	Newcastle-on-Tyne.
William Taylor,	Nottingham.
Thomas Unsworth,	Manchester.
Edward Warner,	Yarmouth.
George Benjamin Wright,	Wolverhampton.

In addition to these there have been twenty-one Resignations of membership.

The Accounts for the year ending 31 December 1887 are now submitted to the Members (*see* pages 10–13), after having been passed by the Finance Committee, and certified by Mr. Robert A. McLean, chartered accountant, the auditor appointed by the Members at the last Annual General Meeting. The receipts during the year were £5,753 15*s.* 7*d.*, while the expenditure, actual and estimated, was £4,787 10*s.* 8*d.*, leaving a balance of receipts over expenditure of £966 4*s.* 11*d.* The financial position of the Institution at the end of the year is shown by the balance sheet: the total investments and other assets amount to £21,001 3*s.* 2*d.*; and allowing £500 for accounts owing but not yet rendered, the capital of the Institution amounts to £20,501 3*s.* 2*d.*, of which the greater part, as seen from the balance sheet, is invested in Railway Debenture Stocks, registered in the name of the Institution. The Corporation Duty, claimed under the "Customs and Inland Revenue Act 1885," appears for the first time in last year's expenditure; and the payment, which has been made under notice of appeal, is for the three years 1885–86, 1886–87, and 1887–88, having previously remained in abeyance pending the appeal by the Institution of Civil Engineers.

The further series of experiments arranged by the Research Committee on Friction, under the chairmanship of Mr. Tomlinson, for determining the friction of a collar bearing, have now been carried out under the direction of Mr. Tomlinson and Mr. John G. Mair by Mr. Beauchamp Tower. The Report of the Committee is presented by the Council for reading and discussion at the present meeting. The experimental apparatus was made at net cost price at the works of Messrs. Simpson and Co., to whom the Research Committee are greatly indebted also for their kindness in obligingly providing free of cost accommodation and engine power and other facilities for enabling the experiments to be carried out in their works.

In the Research upon Riveted Joints, the set of specimen joints made with thicker plates and larger rivets closed under heavier pressures has now been tested by Professor Kennedy, whose Report

to the Committee is in course of preparation. The Research Committee are indebted to the Directors of Lloyd's Proving House at Netherton near Dudley for their kindness in granting the free use of their powerful testing machine for pulling asunder these stronger specimens. The Committee also recall with gratitude the kindness previously recorded of the Landore Siemens-Steel Co. in presenting the whole of the steel plates and rivet bars for the specimen joints, and of Messrs. Fielding and Platt in performing at net cost price the shaping and riveting of the pieces, under the direction of Professor Kennedy and Mr. Ralph H. Tweddell.

The Research Committee appointed to draw up a standard system of Marine Engine Trials have already made some progress towards that object, under the chairmanship of Professor Kennedy; and the measuring tanks are now being constructed for the trials for which the permission of ship-owners has been obtained.

On the value of the Steam Jacket the requisite preliminary work is being done by the Research Committee appointed to enquire into this subject, under the chairmanship of Mr. Henry Davey, with a view to arranging such special practical experiments as shall be found necessary for completing the investigation.

The Library of the Institution has received during the past year the additions enumerated in pages 14–20, for which the Council desire to record their thanks to the several Donors. Continued contributions of books, and of original pamphlets and records of experimental research, are invited for increasing the value of the Library. A new edition of the Library Catalogue having now been issued, Members wishing to supplement any deficiencies which they may discover in the contents of the Library have thus a favourable opportunity for doing so for the benefit of the Institution.

The General Meetings in 1887 were the Annual General Meeting and the Spring Meeting, which were held in London; the Summer Meeting in Edinburgh; and the Autumn Meeting in London. The Papers read and discussed at the seven sittings devoted to the purpose, and published in the Proceedings, were as follows:—

On Triple-Expansion Marine Engines; by the late Mr. Robert Wyllie. (Adjourned Discussion.)

Description of a Portable Hydraulic Drilling Machine; by M. Marc Berrier-Fontaine.

On Copper Mining in the Lake Superior District; by Mr. Edgar P. Rathbone.

Notes on the Pumping Engines at the Lincoln Water Works; by Mr. Henry Teague.

Address by the President: on Fifty Years' Progress in Gun Making.

On the Construction of Canadian Locomotives; by Mr. Francis R. F. Brown.

On the Structure and Progress of the Forth Bridge; by Mr. E. Malcolm Wood.

Notes on the Machinery employed at the Forth Bridge Works; by Mr. William Arrol.

On Electro-Magnetic Machine-Tools; by Mr. Frederick John Rowan.

Description of the Electric Light on the Isle of May; by Mr. David A. Stevenson.

Description of the New Tay Viaduct; by Mr. Fletcher F. S. Kelsey.

On the Dredging of the Lower Estuary of the Clyde; by Mr. Charles A. Stevenson.

On the Improvement of the Clyde above Port Glasgow; by Mr. James Deas.

On Ship Waves; by Sir William Thomson. (Lecture at Conversazione.)

Experiments on the Distribution of Heat in a Stationary Steam-Engine; by Major Thomas English.

Supplementary Experiments on the Initial Condensation in a Steam Cylinder; by Major Thomas English.

The attendances during 1887 were as follows:—at the Annual General Meeting 116 Members and 96 Visitors; at the Spring Meeting 91 Members and 67 Visitors; at the Summer Meeting 276 Members and 65 Visitors; and at the Autumn Meeting 71 Members and 32 Visitors.

For the first time the Summer Meeting of the Institution was held last year in Edinburgh, where, on the invitation of the Chancellor, the Principal, and the Senate of the University, the morning meetings for the reading and discussion of papers took place in their buildings. The Forth Bridge being in progress of construction, and the new Tay Viaduct having then recently been completed and opened for regular traffic, descriptions of these magnificent structures were included among the papers, and visits

were made to them on the invitation of their respective engineers. Many other interesting and important engineering and manufacturing works were also visited in Edinburgh and the neighbourhood, as well as in Dundee, to which busy centre of the jute and other industries a day's excursion was made in connection with the visit to the Tay Viaduct. For the arrangements and hospitalities which gave so much gratification to the Members who took part in the Meeting and the Excursions, the Council are glad to take this opportunity of recording their obligations to the Edinburgh and Dundee Committees, represented by their Chairmen, the Most Honourable the Marquess of Tweeddale and Provost Hugh Ballingall, and their Honorary Secretaries, Mr. St. John V. Day and Professor Ewing. The Conversazione given by invitation of the Lord Provost, the Magistrates, and the Council of the City of Edinburgh, was made the occasion by the kindness of Sir William Thomson for a lucid and instructive lecture on the intricate subject of "Ship Waves," the investigation of which he traced from its commencement to the present time. This lecture is welcomed by the Council as an interesting addition to the Proceedings of the Summer Meeting.

In accordance with the Rules of the Institution, the President, two Vice-Presidents, and five Members of Council, retire from office this day. The result of the ballot for the election of the Council for the present year will be announced to the Meeting.

ACCOUNT OF EXPENDITURE AND RECEIPTS

AND

BALANCE SHEET

FOR 1887.

Dr. ACCOUNT OF EXPENDITURE AND RECEIPTS

Expenditure.	£	s.	d.	£	s.	d.
To Printing and Engraving Proceedings of 1887	870	11	10			
„ Reprinting former Proceedings	58	12	0			
	929	3	10			
Less Authors' Copies of Papers, repaid	19	6	6	909	17	4
„ Library Catalogue revision				45	0	0
„ Stationery, Binding, and General Printing				244	15	7
„ Rent				550	0	0
„ Corporation Duty, 1885–86, 1886–87, 1887–88				70	13	8
„ Salaries and Wages				1,441	0	6
„ Coal, Firewood, and Gas				27	5	0
„ Fittings and Repairs				41	11	11
„ Postages				268	7	10
„ Insurance				5	2	3
„ Travelling Expenses				6	14	7
„ Petty Expenses				50	5	2
„ Meeting Expenses—						
Printing	211	8	4			
Reporting	56	17	2			
Diagrams, Screen, &c.	110	17	11			
Travelling and Incidental Expenses	226	8	7	605	12	0
„ Dinner Guests				69	17	8
„ Research				239	13	11
„ Books purchased				11	13	3
				4,587	10	8
Accounts owing, not yet rendered, say	500	0	0			
Less Reserve in previous year for accounts since paid	300	0	0	200	0	0
Balance, being excess of Receipts over Expenditure, carried down				966	4	11
				£5,753	15	7

	£	s.	d.	£	s.	d.
To Investments—						
£1000 Metropolitan Ry. 3½% Debenture Stock	1,002	12	2			
Forty £25 shares Sir J. Whitworth and Co. bequeathed as per contra, par value	1,000	0	0	2,002	12	2
Cash Balance at this date	1,843	9	6			
Less Reserve to pay accounts not yet rendered, as above	200	0	0	1,643	9	6
				£3,646	1	8

FOR THE YEAR ENDING 31st DECEMBER 1887. *Cr.*

Receipts.	£	s.	d.	£	s.	d.
By Entrance Fees—						
105 *New Members at £2*	210	0	0			
7 *New Associates at £2*	14	0	0			
17 *New Graduates at £1*	17	0	0			
1 *Graduate transferred to Member at £1* . .	1	0	0	242	0	0
,, Subscriptions for 1887—						
1395 *Members at £3*	4,185	0	0			
33 *Associates at £3*	99	0	0			
115 *Graduates at £2*	230	0	0			
1 *Graduate transferred to Member at £1* . .	1	0	0	4,515	0	0
,, Subscriptions in arrear—						
59 *Members at £3*	177	0	0			
9 *Graduates at £2*	18	0	0	195	0	0
,, Subscriptions in advance—						
22 *Members at £3*	66	0	0			
2 *Graduates at £2*	4	0	0	70	0	0
,, Interest—						
From Investments	518	15	7			
From Whitworth Bequest	100	0	0			
From Bank	37	9	0	656	4	7
,, Reports of Proceedings—						
Extra Copies sold				75	11	0
				£5,753	15	7

	£	s.	d.
By Balance brought down	966	4	11
,, Bequest—			
Forty £25 shares Sir J. Whitworth and Co., par value	1,000	0	0
Cash Balance 31st December 1886	1,679	16	9
	£3,646	1	8

Dr. BALANCE SHEET

	£	s.	d.
To Sundry Creditors—			
Accounts owing, not yet rendered, say	500	0	0
Capital of the Institution at this date	20,501	3	2
	£21,001	3	2

Signed by the following members of the Finance Committee:—

EDWARD H. CARBUTT.

JOSEPH TOMLINSON. | ALEXANDER B. W. KENNEDY.
SIR JAMES N. DOUGLASS. | R. PRICE-WILLIAMS.

AS AT 31st DECEMBER 1887. *Cr.*

	£	s.	d.	£	s.	d.
By Cash—*In Union Bank, on Deposit*	1,000	0	0			
„ „ „ *on Current account* . .	343	9	6			
In Imperial Bank	500	0	0	1,843	9	6
„ Investments—			*cost*	15,469	13	8
£ 3,178 *London & N. W. Ry.* 4% *Debenture Stock*						
2,200 *North Eastern* „ „ „ „						
2,466 *Midland* „ „ „ „						
1,800 *Great Western* „ „ „ „						
1,270 *Great Eastern* „ „ „ „						
891 *Metropolitan* „ „ „ „						
2,325 „ „ 3½% „ „						
Forty £25 shares Sir J. Whitworth and Co. Ld.						
Note—The Market Value of these investments at 31st Dec. 1887 was about £17,955.						
„ Subscriptions in Arrear				498	0	0
„ Office Furniture and Fittings				280	0	0
„ Library and Proceedings				2,670	0	0
„ Drawings, Engravings, Models, Specimens, and Sculpture .				240	0	0
				£21,001	3	2

Audited and Certified by

ROBERT A. McLEAN, Chartered Accountant,
1 Queen Victoria Street, London, E.C.

LIST OF DONATIONS TO LIBRARY.

Design of Girder Bridges, by W. Shelford and A. H. Shield; from the authors.

Mechanics of Machinery, by Professor Alexander B. W. Kennedy, F.R.S.; from the author.

Catalogue of Machinery, &c.; from Mr. J. C. R. Okes.

Cantor Lectures on Friction, by Professor H. S. Hele Shaw; from the author.

Reports of the Kew Observatory, 1886 and 1887; from the Committee.

Compressed Air and its Applications, by Norman Selfe; from the author.

Adcock's Engineer's Pocket-Book for 1887; from the proprietor.

Hammer-Blow in Locomotives, by W. H. Booth; from the author.

Formulæ for the Flow of Water in Pipes, by Professor W. C. Unwin, F.R.S.; from the author.

Handbook of information relating to Patents, Designs, and Trade Marks, by Robert E. Phillips; from the author.

Modern War-Ships, by W. H. White; from the author.

Berly's universal Electrical Directory, 1887; from the publisher.

Life and Works of Thomas Graham, D.C.L., F.R.S., by Dr. Angus Smith; from Mr. J. J. Coleman.

Presidential Address on Steam-Engine Economy, by Professor Alexander B. W. Kennedy, F.R.S.; from the Junior Engineering Society.

From the Administration of the Belgian State Railways.

Machine d'Essais du Chemin de fer de l'Etat Belge (système Kirkaldy).

Compte rendu général du Congrès des Chemins de fer, Bruxelles, 1885.

Description sommaire des Types usuels de Locomotives.

Règles à suivre pour la Transmission des Marchandises et des Bagages et le Règlement des Réclamations.

Notice sur les Installations du Chemin de fer de l'Etat à Malines.

Matériel des Transports, recueil spécial des Instructions en vigueur, 1881.

Livret réglementaire du Machiniste.

Règlement pour le Service des Manœuvres, 1884.

Frein continu automatique (système Westinghouse); Description et Instructions.

Machines à Vapeur: Règlement de Police et Instructions.

Instructions sur le Service de l'Eclairage.

Rapport du Jury International, Concours International de Traction Mécanique et de Matériel de Tramways, Anvers, 1885.

Engravings illustrating Belgian Locomotives, 1835–1885.

Engravings illustrating Belgian Rolling Stock.

Photographs of Railway Stations, Workshops, Locomotives, &c., on Belgian State Railways.

Presidential Address to the Society of Engineers, by Professor Henry Robinson; from the author.

Applications of Electricity to Mining Operations, by F. J. Rowan; from the author.

Ueber die Benutzung der Petroleum-Rückstände als Brennmaterial für Locomotiv-Feuerung, by Thomas Urquhart; from the author.

Handbooks of Hotchkiss Rapid-Firing Gun, Mountain Gun, and Revolving Cannon; from Lieut. Edward W. Very.

Gardner Portable Machine-Gun; from the Gardner Gun Company.

Report of Board of Technical Education of New South Wales; from Mr. Norman Selfe.

Problems in Mechanism regarding Trains of Pulleys and Drums of least Weight for a given velocity ratio, by Professor Henry Hennessy, F.R.S.; from the author.

Report on the Trial of Gruson's Chilled Cast-Iron Armour at Spezia, Italy, by Captain D. A. Lyle; from the Ordnance Committee Office, Washington, U.S.

Annual Reports of the U.S. Chief of Ordnance, 1886 and 1887; from the Ordnance Committee Office, Washington, U.S.

Report of Tests of Metals &c. made at Watertown Arsenal, Massachusetts, 1884; from the Ordnance Committee Office, Washington, U.S.

Notes on the Construction of Ordnance, No. 41; from the Ordnance Committee Office, Washington, U.S.

Central-Station Electric Lighting, by Killingworth W. Hedges; from the author.

Architects' Register, 1887, vols. I and II; from Mr. W. Pope.

Address on the Work of the Imperial Institute, by Sir Frederick Abel, C.B., F.R.S.; from the author.

Address by the Rector of the Royal Technical High-School, Berlin; from the author.

Shafting of Screw Steamers, by Hector MacColl; from the author.

Practical Engineer's Handbook, by Walter S. Hutton; from the author.

British Iron Trade Report, 1886; from Mr. J. S. Jeans.

System in Engineering Works, by Hans Renold; from the author.

List of Chinese Lighthouses, Light Vessels, Buoys, and Beacons, 1887; from the Inspector-General of Chinese Customs.

Recherches théoriques et expérimentales sur les Oscillations de l'Eau et les Machines Hydrauliques à colonnes liquides oscillantes, by the Marquis A. de Caligny; from the author.

Papers relating to the Palar Anicut System; from the India Office.

Entwickelung der Pneumatischen Fundirungs-Methode, by Ernst Gaertner; from the author.

Address on the Relation of Chemistry to Engineering, by Professor H. E. Armstrong, F.R.S.; from the Junior Engineering Society.

Water Supplies suited to Farms and Villages, by William Anderson; from the author.

Presidential Address to the Association of Municipal and Sanitary Engineers and Surveyors, by Joseph Gordon; from the author.

Papers on Education, read at the Conference of Architects, May 1887; from Mr. Arthur Cates.

Cable or Rope Traction, by J. Bucknall Smith; from the editor of "Engineering."

Roller Mills, by Rhys Jenkins; from the author.

Proceedings of the American Academy of Arts and Sciences, vol. xx, 1885; from Mr. William Watson.

Budget Speech, by the Hon. Sir Charles Tupper, C.B.; from the Canadian Government.

Expansion of Structures by Heat, by John Keily; from the publisher.

Hydrodynamic Theory of Friction in Machinery (3 parts), by Professor N. Petroff; from the author.

Ueber die Möglichkeit einer genauen Kreisbogenverzahnung, by Professor N. Petroff; from the author.

Classified List and Distribution Return of Establishment, Indian Public Works Department, to 30 June 1887; from the Registrar.

Annual Report of the Yorkshire College, Leeds, 1886–7; from the College.

Forth Bridge, by Reginald E. Middleton; from the author.

Civil Engineer's Pocket-Book, by John C. Trautwine, 1887; from Mr. John C. Trautwine, Jun.

Calculating the cubic Contents of Excavations and Embankments by the aid of diagrams, by John C. Trautwine; from Mr. John C. Trautwine, Jun.

Field Practice of Laying out Circular Curves for Railroads, by John C. Trautwine; from Mr. John C. Trautwine, Jun.

Experimental Enquiry concerning the Natural Powers of Wind and Water to turn Mills and other Machines depending on a Circular Motion, by John Smeaton; from Mr. Bryan Donkin.

Power of Machines, by John Banks; from Mr. Bryan Donkin.

Travaux Hydrauliques de Louis Alexandre De Cessart; from Mr. Bryan Donkin.

Civil and Mechanical Engineering popularly and socially considered, by J. W. C. Haldane; from the author.

Report on the Organisation and Administration of the Manufacturing Departments of the Army; from the Secretary of State for War.

Metallurgy of Silver, Gold, and Mercury, in the United States (vol. I), by Thomas Egleston, LL.D.; from the editor of "Engineering."

Boiler Incrustation and Corrosion, by F. J. Rowan; from the author.

Études sur les Machines à Vapeur, by Auguste Taurines; from the author.

Ninth Annual Report of the National Association of British and Irish Millers; from the Association.

Calendars for 1887–88, from the following Colleges:—City of London College; Durham College of Science, Newcastle-on-Tyne; University College, Bristol; University College, Dundee; University College, London; and Yorkshire College, Leeds.

Handbook for Steam Users, by M. Powis Bale; from the author.

Photograph of 67-inch Rope-Driving Pulley; from Mr. Daniel Longworth.

Village Water Supply, by Stephen H. Terry; from the author.

History of the Royal United Service Institution, by Captain Boughey Burgess; from the author.

Report on Weights and Measures, 1887; from the Board of Trade.

Presidential Address on an Engineer's Education, by William Anderson; from the Junior Engineering Society.

Life of Robert Stevenson, Civil Engineer, by David Stevenson; from Mr. David A. Stevenson.

Ein Ingenieurtag in England und Besichtigung der Brücken über den Firth of Tay und Firth of Forth, by Ernst Gaertner; from the author.

Architect's, Surveyor's, and Engineer's Compendium for 1888; from the publisher.

Rapport du Comité de l'Industrie, Exposition universelle d'Anvers 1885; from Mr. William Anderson.

The following Publications from the respective Societies and Authorities:—

Reports of the Academy of Science, France.

Reports of the Royal Academy of Science, Belgium.

Reports of the Royal Institute of Engineers, Holland.

Engravings from the École des Ponts et Chaussées, Paris.

Annales des Ponts et Chaussées, Paris.

Proceedings of the French Institution of Civil Engineers.

Journal of the French Society for the Encouragement of National Industry.

Journal of the Marseilles Scientific and Industrial Society.

Annales de l'École Polytechnique de Delft.

Proceedings of the Engineers' and Architects' Society of Canton Vaud.

Proceedings of the Engineers' and Architects' Society of Austria.

Proceedings of the Architects' and Engineers' Society of Hannover.

Proceedings of the Engineers' and Architects' Society of Prague.

Proceedings of the Italian Engineers' and Architects' Society.
Proceedings of the Engineers' and Architects' Society of Milan.
Proceedings of the Industrial Society of Mulhouse.
Proceedings of the Industrial Society of the North of France.
Proceedings of the German Society of Engineers.
Proceedings of the Russian Imperial Institute of Engineers.
Proceedings of the Swedish Society of Engineers.
Journal of the Norwegian Technical Society.
Bulletin de la Commission Internationale du Congrès des Chemins de fer, Bruxelles.
Journal of the Franklin Institute.
Transactions of the American Society of Civil Engineers.
Transactions of the American Society of Mechanical Engineers.
Transactions of the American Institute of Mining Engineers.
School of Mines Quarterly, Columbia College, New York.
Report of the Smithsonian Institution.
Report of the Master Car-Builders' Association, New York.
Proceedings of the United States Naval Institute.
Report of the United States Geological Survey.
United States Patent Office Gazette.
Transactions of the Canadian Society of Civil Engineers.
Professional Papers on Indian Engineering; from the Thomason College.
Proceedings and Journal of the Asiatic Society of Bengal.
Proceedings of the Engineering Association of New South Wales.
Proceedings of the Institution of Civil Engineers.
Journal of the Iron and Steel Institute.
Transactions of the Society of Engineers, with General Index 1861–1885.
Journal of the Society of Telegraph-Engineers and Electricians.
Transactions of the Institution of Civil Engineers of Ireland.
Transactions of the North of England Institute of Mining and Mechanical Engineers.
Proceedings of the South Wales Institute of Engineers.
Transactions of the Institution of Engineers and Shipbuilders in Scotland.
Transactions of the Chesterfield and Midland Counties Institution of Engineers.
Transactions of the Liverpool Engineering Society.
Transactions of the Midland Institute of Mining, Civil, and Mechanical Engineers.
Proceedings of the Cleveland Institution of Engineers.
Transactions of the West of Scotland Mining Institute.
Transactions of the North-East Coast Institution of Engineers and Shipbuilders.
Transactions of the Hull and District Institution of Engineers and Naval Architects.

Proceedings of the Royal Society of London.
Proceedings of the Royal Institution of Great Britain.
Transactions of the Surveyors' Institution.
Transactions of the Sanitary Institute of Great Britain.
Journal of the Royal United Service Institution, with Index to vols. xxi–xxx.
Professional Papers of the Royal Engineers' Institute.
Proceedings of the Royal Artillery Institution.
Journal of the Royal Agricultural Society of England.
Journal of the Royal Statistical Society.
Report of the British Association for the Advancement of Science.
Report of the Royal Cornwall Polytechnic Society.
Transactions of the Institution of Naval Architects.
Transactions of the Royal Institute of British Architects.
Transactions of the Gas Institute.
Proceedings of the Physical Society of London.
Transactions of the Manchester Geological Society.
Journal of the Royal Scottish Society of Arts.
Proceedings of the Philosophical Society of Glasgow.
Transactions and Proceedings of the Royal Irish Academy.
Transactions and Proceedings of the Royal Dublin Society.
Journal of the Liverpool Polytechnic Society.
Journal of the Society of Arts.
Journal of the Society of Chemical Industry.
Reports of the Manchester Steam Users' Association; from Mr. Lavington E. Fletcher.
Midland Steam Boiler Inspection and Assurance Company, Records of Boiler Explosions in 1876, 1877, 1879, and 1886; from Mr. Edward B. Marten.
Report of the National Boiler Insurance Company; from Mr. Henry Hiller.
Report of the Engine, Boiler, and Employers' Liability Company; from Mr. Michael Longridge.
Boiler Insurance and Steam Power Company, Manchester, Reports for 1859–1862, 1864, 1865, 1874, and 1875; from Mr. Niel McDougall.
Report of the London Association of Foremen Engineers and Draughtsmen.
Proceedings of the Manchester Association of Engineers.
Thirty-fourth Annual Report of the Liverpool Free Public Library.
Sixth Report, and Catalogues, of the Newcastle-on-Tyne Public Library.
Fifth Annual Report of the Barrow-in-Furness Free Public Library.
Thirty-third and Thirty-fourth Annual Reports of the Bolton Public Free Library.

The following Periodicals from the respective Editors :—

Revue générale des Chemins de fer.
Revue universelle des Mines.
Revue Industrielle.
Portefeuille économique des Machines.
Stahl und Eisen.
Der Civil-Ingenieur.
Glaser's Annalen.
Giornale del Genio Civile.
Ingeniero y Ferretero Español y Sud Americano.
The Railroad Gazette.
The American Engineer.
The American Manufacturer.
The Engineering and Mining Journal.
The National Car and Locomotive Builder.
The Railroad and Engineering Journal.
The Railway Master Mechanic.
The Indian Engineer.
The Engineer.
Engineering.
The Railway Engineer.
The Marine Engineer.
Iron.
The Iron and Coal Trades Review.
Ryland's Iron Trade Circular.
The Ironmonger.
The Mechanical World.
The Mining Journal.
The Colliery Guardian.
The Machinery Market.
The Builder.
The Builders' Weekly Reporter.
The Electrical Review.
The Electrical Engineer.
The Chamber of Commerce Journal (from Mr. Henry Chapman).
The Contract Journal.
The Gas and Water Review.
The Gas World.
The Plumber and Decorator.
The Shipping World.
The Fireman.
Industries.
Invention.
The Universal Engineer.
The Railway Record.
The British Trade Journal.
The Practical Engineer.
Electrical Plant.
Scientific News.
Mechanical Progress.
Martineau and Smith's Hardware Trade Journal.
Phillips' Monthly Machinery Register.
The Intelligence Quarterly.

The President, before moving the adoption of the Annual Report of the Council, wished to make a few remarks on the position of the Institution and on the papers that had been read. He thought the Members would agree with him that the Institution had done very good and useful work during the past year. The mere fact that the increase in the number of Members was double that of the previous year showed that the engineers of the country were appreciating the efforts which the Institution was making to put engineering on a proper basis and to spread information through all ranks of the profession. Unfortunately bad trade had told upon a great many Members, some of whom had resigned in consequence; but he trusted that when things got better they would return, and find that it was worth while to pay their subscription and get the information which the Institution afforded. It would be observed that one new item of expenditure had made its first appearance in the accounts under the head of taxes; the Institution had had to pay corporation duty for three years in one year. The question whether scientific institutions of this kind should pay corporation duty was being fought out by the Institution of Civil Engineers; and although the case had gone against them so far, he understood it was to be carried to a higher court, and if necessary to the House of Lords. The Institution of Mechanical Engineers considered that they were an educational institution and ought not to be taxed.

As showing that mechanical engineers were appreciated not only in England but in other parts of the world, he might refer to the fact that Her Majesty had been pleased to make a Member of the Institution, and a former President, a peer of the realm in the person of Lord Armstrong, and that the government had done him the honour of asking him to second the Address in the House of Lords. Her Majesty had also conferred the honours of baronetcy or knighthood on several Members of the Institution, including during last year Sir Douglas Galton and Sir John Smith of Derby, the latter of whom he was very glad to see present on this occasion. Members abroad also had been earning distinction for themselves; he had yesterday received a telegram from Mr. Thomas Elwell of Paris, announcing that he had just been nominated a Chevalier de

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la Légion d'Honneur, which he believed was a very high honour, and one seldom conferred on an Englishman; it was not only an honour conferred upon Mr. Elwell himself but also an honour to the Institution. In France it was well understood that engineers were of some advantage to their country, for the present President, M. Carnot, was an engineer of the Ponts et Chaussées; it was evident that, if an engineer was capable of managing the whole of France, engineers were capable of doing some good in the world.

Of the papers discussed during the past year the first was that of the late Mr. Wyllie on triple-expansion marine engines, which to his mind showed the advantage of occasionally having slack trade, for this often drove men to use their wits. Shipowners all over the world had been finding that they could not carry with advantage and profit to themselves; and the consequence had been that engineers had set to work, and by means of triple-expansion engines had made it possible for shipowners to earn a dividend. In the discussion on that paper Mr. William Parker of Lloyd's had mentioned that the economy of the triple-expansion engine just made the dividend to one company; and another case was mentioned by Mr. Morison in which a steamer on a return Australian voyage had saved £1000 in fuel by the use of triple-expansion engines; and another steamer going to the Cape and back had saved at the rate of £3000 a year by the same means. Only recently he observed that one of the Orient liners, the "Cuzco," had been supplied with triple-expansion engines; and that, whereas she formerly went at a speed of 12½ knots an hour, she was now able to run 16 knots with a decreased consumption of fuel. This showed the immense field there was for the work of engineers, because if the old ships were to run they were bound to have new engines, and that would find work for engineers and put them in better spirits. They ought therefore to be very thankful to Mr. Wyllie, who had brought before them the subject of economy of fuel on board ship, because his paper had been the means of having it thoroughly ventilated.

The next paper to which he wished to allude was that by Mr. Rathbone on the Lake Superior copper mining district. Since it was read, copper had run up from £38 10*s*. to nearly £80 a ton,

although it was rather lower at the present time. The mines in the Lake Superior district had yielded 36,000 tons of copper in the year 1885, which was very nearly half the whole production of 74,000 tons in the United States, or nearly one-sixth of the total production of 223,500 tons in the whole world. Unfortunately a very bad accident had since taken place there. The paper had given a graphic account of how the levels were held up by timbers 12 inches square or more, all braced together. A fire had lately broken out in the Calumet and Hecla mines, and all that underground forest of timber was now being burnt out. The consequence was that these mines, which produced 23,600 tons or nearly one-ninth of the total production of copper in the world, had not been able to produce any. At the end of last year there was a reduction of 20,000 tons in the stock of copper, which, coupled with the loss of production from the Calumet and Hecla mines, was some reason for the price of copper running up.

The paper from Mr. Teague on the Lincoln waterworks engines had led to a good discussion. Several of the engineers from the different London waterworks had been present and had given useful information on the subject. It was a very good thing if engineers who had not time to write papers for the Institution would come to the meetings and give their experience in the discussions upon the papers read.

There had also been a very interesting paper from Mr. Brown on Canadian locomotive practice, which had revived a controversy that was by no means disposed of in the discussion. It brought into prominence the advantages of a flexible or elastic wheel-base, and also the extensive use of cast iron in the construction of American locomotives, and the preference so largely entertained for the bar-frame. As there had previously been two very good papers on compound locomotives—one by a Russian Member, M. Alexander Borodin, on the practice on the Russian South Western Railways, and the other by Mr. Sandiford on the practice in India—he hoped that the vexed question of compounding locomotives would soon be taken up again by some member of the Institution, because it was necessary that it should be fought out. There were many engineers who did not believe that the economy obtained by compounding

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locomotives was worth the trouble and expense of altering them. Two of the largest railways in this country however—the North Western on the one side and the North Eastern on the other—were using compound locomotives. He hoped that Mr. Worsdell, as a member of the Council, or some other Member of the Institution, would see his way to offer a paper on the subject, because the question ought to be thoroughly discussed in the interest both of the railways and of engineers.

Then there had been two papers on electro-magnetic machine-tools, and on the Isle of May electric lighthouse. The Members who attended the Edinburgh Meeting, and went to the Isle of May lighthouse, must have been delighted with their trip and have profited by what they saw.

The last paper to which he wished to allude was that by Major English, which practically consisted of two papers. He was very glad when government engineers occupying a position like that of Major English contributed such a paper as his, which brought out such valuable facts with regard to the distribution of heat in steam cylinders. It appeared from the paper however that the relative efficiency of the engines experimented upon was only about 40 per cent.; which showed that there was great scope for engineers to do something more than they had yet done in favour of economy of steam.

This brought him to the subject of Research Committees. The Council thought that with the money they had at command—for they were putting by nearly £1000 a year, and until they built a house for the Institution they would probably continue to do so—it was their duty to do all they could to encourage these research committees, for which he believed there was great room, in view of the difficulty of getting at accurate facts or data. A long discussion, for example, was just now going on in the engineering press as to the data on which the engine trials of the Royal Agricultural Society were based; and for the settlement of this vexed question it was necessary that the facts of frictional resistance should be thoroughly determined practically. The Members were therefore greatly obliged to Mr. Tomlinson, Mr. Mair, and other Members of the Institution, who had taken so much trouble in determining the rules

which governed friction. Another question was that of riveting, especially for very thick plates. The fact that marine-engine boilers were now working up to 150 lbs. pressure per square inch showed that very good riveting was wanted. On that subject Professor Kennedy and his committee were doing good work. The questions also of steam-jacketing and of marine-engine trials had been taken up by committees of which Mr. Davey and Professor Kennedy were the chairmen. He thought the Members would see that the Council had been endeavouring to carry out their views in a proper way.

The Summer Meeting in Edinburgh had been a great success, and had fortunately been favoured with very fine weather. Sir John Fowler and Mr. Baker who were building the Forth Bridge, and Mr. Barlow who had built the Tay Bridge, had been very kind in showing everything that could possibly be seen of their great works. The Members would all wish Sir John Fowler and Mr. Baker every success in completing the Forth Bridge, and trust that this great engineering monument of the age would reflect credit on the profession.

In continuation of the address which he had given at the Spring Meeting, he should be glad to take this opportunity of saying a few words more on the same subject. In that address he had traced the progress which had taken place in gun-making during the last fifty years, and had shown what was the organisation at the time. Since then the committee upon which he had had the honour to sit, under the chairmanship of Lord Morley, had reported; and he thought it would be well that the attention of mechanical engineers should be called to their report. The protection of England was a mechanical question in every sense of the word. England had the smallest army in the world for a nation of anything like her size, and she had the largest number of ships to protect. If therefore she did not see that her guns were thoroughly efficient, she would not be able to maintain her position in case of war. Considering that Germany was talking of increasing her war armaments, and putting her army on a war footing by an addition of 700,000 men and at a cost of £14,000,000, he thought this country ought to look to her position. In an interesting paper lately read before the London Chamber of

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Commerce by Lord Brassey, who had just returned from a tour round the world, there were two or three points to which he should like to call the attention of the Members. He had himself said repeatedly that England had not a sufficient number of guns for the defence of her empire; and the same fact had now been brought forwards by Lord Brassey, who had shown that the weak point in our defence was that we had not a sufficient number of guns. Lord Brassey had referred to the coaling stations, and had mentioned particularly two places where the guns were old-fashioned and inefficient, namely Bombay and the Cape. In regard to Bombay Harbour he stated—"The works are undergoing complete transformation; light guns are being removed, and 38-ton guns, to be ultimately replaced by breech-loading guns, are being mounted." It appeared to him great waste of money to send muzzle-loading guns abroad and fix them, and then in a year or two to have to take them out, and put in breech-loading guns; it was far better to put down proper guns at the outset. Referring to the guns at Cape Town, Lord Brassey said—"At the date of my visit apprehensions were felt by the local authorities at the Cape that the number of breech-loading guns to be supplied by the Imperial Government would not be sufficient; it was in contemplation to mount the old-pattern guns in the newly-constructed forts." It thus appeared that two of the most important stations were protected by old-fashioned guns; and he hoped that by ventilating this subject before the country a feeling would be awakened that there ought to be a proper supply of guns of the latest design. Such a supply could be obtained if a little time were given, and if the steel manufacturers who had been encouraged to put down large steel plant and powerful hydraulic presses had more orders given them. When the forging presses and hammers that were now being put down were ready, they would be able to supply three or four times the amount of forgings required by the government, and it would only further be necessary for proper arrangements to be made to get these converted into guns. This could be done by employing private manufacturers to turn and bore the forgings, sending the finished tubes to Woolwich to be put together. After having sat eighteen months and made a very exhaustive enquiry, the

conclusion at which Lord Morley's committee had arrived was that Woolwich, instead of being divided into three separate departments as hitherto, should be placed under one supervision, and made as it were one factory. The committee believed that the right thing was that there should be a separate inspection department. Outside contractors should not be able to say that the officers at Woolwich had the power to inspect their own guns and pass them, even if the material was not quite up to the mark. There was no reason why private manufacturers should be more hardly dealt with than those at Woolwich. There ought in all cases therefore to be a separate inspection, which would give confidence both to manufacturers and to the public that only reliable guns were passed into store.

The main gist however of the committee's report was in the first two recommendations, which ran as follows:—"(1) That a Superintendent of Ordnance Factories should be appointed, holding office under the Director of Artillery and Stores. He should be an officer of the army, and should reside at Woolwich. He should be the sole channel of communication between the war office, and the manufacturing departments. In addition to the general superintendence of the factories, he should be the head of the designing and drawing office. (2) Subject to the control of this officer, there should be a Chief Mechanical Engineer holding a civilian appointment, who should be in charge of and responsible for manufacture in all its branches. His subordinates, also civilians, should take charge of the various departments."

The government had undertaken to re-organise Woolwich, and had appointed Colonel Maitland as the chief, and he thought they could not have appointed a better man; he would be able to do a great deal to consolidate the separate departments. Unfortunately however they had not appointed a mechanical head. Unless they carried out the scheme in its entirety, and had a mechanical engineer to manage the shops in a mechanical way, it was of little use to put a military man at the head of the department that he might endeavour to re-organise it. If they had a mechanical engineer, he would increase the out-put by joining all the three portions of Woolwich into one concern. At the same time an engineer with the best

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mechanical talents ought to be paid properly. But what was the actual state of the case at present? In one of the departments at Woolwich, with between 5000 and 6000 men, there was a manager in charge who was responsible for this large number of men, and responsible for all the piece-work prices amounting to several thousands, having the design of all the machinery required, and practically passing or receiving all the material into the department, so that he had the power to order a large amount of machinery and stores; yet with all this responsibility upon him he had a salary of only £440 a year. On enquiring further into the matter it was ascertained that he had a house in addition; but then it was also discovered that the chief clerk of the very same department had £650 a year. This certainly seemed unreasonable, because here the chief clerk had no responsibility such as rested upon the chief clerk of a private firm, who had to see that no bad debts were made, and had to look after all the money paid for material and wages. Unless men were paid properly he believed the proper men would never be got for managing such concerns in the most efficient manner. It might be said that by persuading such men that they ought to be better paid he was urging the government to be more extravagant, while their policy ought to be in favour of economy; but he could assure the government that they could pay better salaries without any loss. Having himself looked into the question of workshop useable stores, such as tool steel, files, bar iron, copper, etc., he had found that the stores were crammed with a tremendous stock, twice or three times as much as necessary. The authorities were not content with one month's supply, such as an ordinary manufacturer kept, but there was more than a year's supply, in some cases two years', in other cases three, and even up to five years' supply of material in the stores, the average of the whole being nearly two years' supply. In these days such a stock was altogether unreasonable, because by means of the telegraph any article wanted could easily be got by train on the following morning. The useable stores at Woolwich alone represented £460,000. With a mechanical engineer at the head who would manage the concern properly, all the useable stores that would be required would not

represent £100,000; and the interest on the difference between £100,000 and £460,000 would be sufficient to pay a good salary to a chief mechanical engineer. He felt so strongly on this subject that his own intention was to continue doing everything he could, in season and out of season, until the manufacturing departments of the government were placed upon a proper footing; and he hoped that the Members of the Institution would exert their efforts in every possible way, and back up the principle that if the workshops were to be properly managed there must be at their head a professional engineer. He had not a word to say against the military men, who were very good in their place; but they had not had large workshop experience, and could not go into details as a workshop manager would do. By consolidating the three departments at Woolwich and placing them under one responsible head, the government would do away with what had been a very great source of loss. Instances had occurred in which gun-carriages had been made and the guns had not fitted them. Only lately a disappearing gun-carriage had been ordered for a given weight of gun, and when the gun and carriage were finished it was found that the gun was five tons heavier than ordered; consequently the carriage had to be altered at an expense of £500 or £600. If there were a good mechanical engineer at the head, nothing of that kind could happen.

He had now great pleasure in moving the adoption of the Annual Report of the Council, which he hoped would meet with the approval of the Members.

The motion was unanimously agreed to.

The President announced that the Ballot Lists for the election of Officers for the present year had been opened by a committee of the Council, and that the following were found to be elected:—

PRESIDENT.

Edward H. Carbutt, . . . London.

VICE-PRESIDENTS.

Daniel Adamson, ... Manchester.
Joseph Tomlinson, ... London.

MEMBERS OF COUNCIL.

Sir James N. Douglass, F.R.S., . .	London.
Sir Douglas Galton, K.C.B., F.R.S., .	London.
Alexander B. W. Kennedy, F.R.S., .	London.
E. Windsor Richards, . . .	Middlesbrough.
T. Hurry Riches, ...	Cardiff.

The Council for the present year will therefore be as follows:—

PRESIDENT.

Edward H. Carbutt, . . .	London.

PAST-PRESIDENTS.

The Right Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., . .	Newcastle-on-Tyne.
Sir Lowthian Bell, Bart., F.R.S., .	Northallerton.
Sir Frederick Bramwell, D.C.L., F.R.S.,	London.
Thomas Hawksley, F.R.S., . .	London.
Jeremiah Head, ...	Middlesbrough.
John Ramsbottom, ...	Alderley Edge.
John Robinson, ...	Manchester.
Percy G. B. Westmacott, . .	Newcastle-on-Tyne.

VICE-PRESIDENTS.

Daniel Adamson, ...	Manchester.
Charles Cochrane, ...	Stourbridge.
David Greig, ...	Leeds.
Arthur Paget, ...	Loughborough.
Richard Peacock, M.P., . . .	Manchester.
Joseph Tomlinson, ...	London.

MEMBERS OF COUNCIL.

William Anderson, ...	London.
Benjamin A. Dobson, . . .	Bolton.
Sir James N. Douglass, F.R.S., .	London.
Sir Douglas Galton, K.C.B., F.R.S., .	London.
Samuel W. Johnson, . . .	Derby.
Alexander B. W. Kennedy, F.R.S., .	London.
William Laird, ...	Birkenhead.

Edward B. Marten, ...	Stourbridge.
Edward P. Martin, ...	Dowlais.
Sir James Ramsden, ...	Barrow-in-Furness.
E. Windsor Richards, . . .	Middlesbrough.
T. Hurry Riches, ...	Cardiff.
Benjamin Walker, ...	Leeds.
J. Hartley Wicksteed, . . .	Leeds.
Thomas W. Worsdell, . . .	Gateshead.

The President said he was much obliged to the Members for the honour they had done him in re-electing him President for another year. If it had not been for the assistance of the Council, who had done so large a part of the work, he was afraid that he should not have been able to do his own share so well as to lead the Members to elect him a second time.

The President said it was now the duty of the Members to appoint an Auditor for the present year.

On the motion of Mr. Frederick Colyer, seconded by Mr. Henry Chapman and supported by Mr. E. B. Ellington, it was unanimously resolved that Mr. Robert A. McLean, chartered accountant, 1 Queen Victoria Street, London, be re-appointed to audit the accounts of the Institution for the present year, at a remuneration of Ten Guineas, being the same as heretofore.

The President announced that the Summer Meeting of the Institution in the present year would be held in Dublin; and from what he had heard he believed the Members would have a very good reception there. The Summer Meeting having been held the year before last in London, and last year in Edinburgh, it had naturally been considered by the Council that it ought to take place this year in Dublin, so that the Members in Ireland might not be able to feel that they had been neglected.

The Adjourned Discussion upon the following Paper read at the Autumn Meeting was then resumed, and completed:—

On Irrigating Machinery on the Pacific Coast; by Mr. JOHN RICHARDS, of San Francisco.

The following Paper was then read and partly discussed:—

On the Position and Prospects of Electricity as applied to Engineering; by Mr. WILLIAM GEIPEL, of Edinburgh.

Shortly after Ten o'clock the Discussion was adjourned till the following evening. The attendance was 92 Members and 56 Visitors.

The ADJOURNED MEETING of the Institution was held at the Institution of Civil Engineers, London, on Friday, the 3rd of February 1888, at Half-past Seven o'clock p.m.; EDWARD H. CARBUTT, Esq., President, in the chair.

The Discussion on Mr. Geipel's Paper on the Position and Prospects of Electricity as applied to Engineering, which had been commenced on the previous evening, was resumed and completed.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers for their kindness in granting the use of their rooms for the Meeting of this Institution.

The Meeting then terminated shortly after Ten o'clock. The attendance was 79 Members and 66 Visitors.

ON IRRIGATING MACHINERY ON THE PACIFIC COAST.

By Mr. JOHN RICHARDS, of San Francisco.

In offering the present paper to the Institution of Mechanical Engineers the author does so with a tolerably complete knowledge of the very advanced practice in England in this class of machinery; and his purpose is mainly to explain the differences that have been called for by local circumstances in California.

Character of the Country.—The western or Pacific slope of the Sierra Nevada or coast range of mountains in California is very abrupt, the crests of the range being so near that the snow is visible from the coast during the whole year. Hundreds of streams cross this narrow country, falling either direct into the Pacific ocean or into the great basin formed by the Sacramento and San Joaquin rivers. These two rivers, the largest in California, run in opposite directions, nearly parallel with the coast, and meet at the Bay of San Francisco, forming a continuous valley 400 miles long and from 50 to 100 miles wide. The small streams for the most part are fed by melting snow in the summer; and every gulch or cañon has its rivulet or brook. They increase in volume until they pass into or through the hills at the foot of the mountain range; and there, unless of considerable size, they may wholly disappear in summer by percolation through the silt or by evaporation. Streams exposed to the torrid air which in summer sweeps across the sand deserts of southern California are dried up with wonderful rapidity. The evaporation from Salt Lake, exposed to the same dry wind, is sometimes equal to half an inch per day, or 64 million tons of water. Notwithstanding this great loss by evaporation, the quantity of water falling into the ocean on the coast of California has been estimated at 100 million cubic feet or $2\frac{3}{4}$ million tons per

minute, enough if distributed properly to irrigate 25,000 square miles.

The Pacific coast in California may be said to consist of a mountain slope, fissured everywhere by water; and of alluvial plains formed by the sediment deposited from the water, which varies from coarse gravel and sand to fine silt, as the velocity and volume of the water courses have determined. Nearly the whole country is therefore underlaid with strata of sand and gravel, which afford water everywhere at various depths.

The need of irrigation arises from three causes:—the lack of rain, which in summer ceases wholly along the coast; the want of surface water; and the free percolation into the sand beneath. The area requiring irrigation comprises most of the land in the country, except the low-lying sedimentary plains near the mouths of the rivers, and around the Bay of San Francisco, where water reaches the surface by capillary saturation.

Water Training.—In the days of placer gold-mining, a large part of the running water in the mountains and foot hills was collected in extensive ditches, flumes, and iron pipes; the water was as important as the gold, which could not be washed out without it. Placer mining is gone; but the ditches remain, most of the water now being required for the more permanent business of fruit growing and other kinds of agriculture. Perhaps no part of the world equally rugged and difficult of access has been so thoroughly explored and mapped as this. From the tops of the mountain ridge to the depths of the cañons there is scarcely an acre that has escaped the search for gold and silver. The information thus acquired respecting the surface of the country was made use of as soon as agriculture began to receive attention; and the result is that nearly all land is now occupied upon which water can be led, not only by training small mountain streams, but also by leading long canals, or ditches as they are called, from the rivers; until at the present time, or when works now in hand are completed, the only remaining resource for getting water will be by lifting it from the rivers or the gravel strata by machinery.

Character of the Machinery required.—The standard methods of raising water for irrigation and drainage, commonly adopted in the Netherlands and elsewhere, would not apply on the Pacific coast. Permanent foundations are wanting; a number of small separate pumping stations, widely distributed, are required, instead of a few large establishments centrally situated; and a high efficiency is essential in the machinery employed, because of the high cost of fuel, coals of indifferent quality being worth from 30*s.* to 40*s.* a ton. For raising 420,000 gallons per hour from 6 to 10 feet high the cost of the machinery is from £500 to £600. For raising 1,000,000 gallons per hour from 10 to 14 feet high the cost is from £800 to £1,000, including engines, boilers, pipes, and framing. This must account for the light sections and other scant proportions that will be observed in the drawings; material enhanced in value 40 to 50 per cent. by tariff taxes is of course used sparingly. An efficiency of 65 to 70 per cent. is attained in most cases when the head or lift is between 8 and 16 feet. For pumping from deeper wells the machinery is much more expensive, in proportion to the quantity of water raised, both because of the greater length of the driving connections to the pumps, which are placed in the bottom of pits in order to be within suction distance of the water, and also because of the greater strength required in all parts to stand the speed and pressure.

Fruit farms, on account of the labour and attention they require, are limited in size; and irrigating machinery must come within moderate limits of cost. Where the water is drawn from the gravel, concentration of pumping is out of the question. Percolation is not free enough to admit of large quantities being raised at one point and distributed; and even if this were possible, adjacent wells would be robbed, and litigation might ensue. In some experiments at San José, California, during the year 1885, it was found that, in drawing 15,000 gallons per hour from two artesian wells of 10 inches diameter and 200 feet depth, neighbouring wells at distances of from 200 to 600 yards were lowered. In this instance the water rose naturally to 2½ feet above the surface of the ground at the wells, and was lowered only 6 feet by drawing 15,000 gallons

per hour. The wells here referred to, and indeed nearly all wells in irrigated districts, are tubes of sheet iron from 6 to 14 inches diameter, sunk by forcing, the earth being removed through the interior of the tubes.

In the broad alluvial plains along the Sacramento river, and especially in places near to its banks, percolation is so rapid that some attempt has been made at concentration of pumping plants. One well of 40 feet diameter and 16 feet depth, having an infiltrating surface of 1,000 to 1,200 square feet, yields 180,000 gallons an hour; and others of smaller infiltrating area yield a proportionate quantity. But these are in places where the water-bearing strata are much thicker than usual, the gravel coarse, and the saturation greater than in most other parts of the country.

Early Irrigating Machinery.—One of the earliest appliances for raising water in California was the Chinese pump, illustrated in Fig. 1, Plate 1, which consists of an endless band travelling round pulleys at top and bottom of a moderate slope, and carrying a series of wooden floats or crossbars fixed on its outer face; the under span ascending through an open trough carries up water from a ditch or pit and delivers it into a launder or flume at top. The endless bands are sometimes made of india-rubber or cotton canvas; but more commonly consist of a pair of ropes, upon which the crossbars, having their ends split, are clamped at regular intervals by means of screws. It is a very cheap contrivance, and for low lifts is still employed to a considerable extent by the Chinese and Italians; it was doubtless introduced into California by the Chinese in imitation of similar pumps extensively used in China for raising water from the canals, where the lift is only a few feet. For slopes not steeper than 20 degrees, and lifts of only from 3 to 6 feet it is found to be very economical in cost of working; and is said to be capable of high duty when the wooden floats or crossbars are so arranged and proportioned as to render the rising span nearly buoyant in the water, and especially when the inside of the trough is lined with metal to diminish the friction. For irrigation these pumps are commonly driven by horses, and for other purposes are employed only

temporarily: and so far as the writer knows no experiments have been made to determine their real efficiency. For lifts exceeding 10 feet and slopes steeper than 30 degrees, the friction and leakage render them unsuitable; and their use is being abandoned as better methods are introduced.

Tube-Well Pumps.—These pumps, or the method of constructing them, grew out of the oil-well experience in the Atlantic States. In Fig. 2, Plate 1, is shown a common method of working such pumps by means of a beam and engine. The tubes or barrels T, which constitute both well and uptake, are made of galvanised iron, from No. 18 to No. 14 B.W.G., or 0·050 to 0·085 inch thick, with the longitudinal seams riveted and soldered together throughout. They are made from 6 to 14 inches in diameter; and are sunk to depths varying from 100 to 200 feet, sometimes more when pure water is wanted. The water rises in the wells to heights varying with different seasons; and in some cases overflows at the surface, as in the well at San José already mentioned. The pumps are placed at different depths accordingly. For irrigation the wells are generally arranged in a quadrangle when there are four; or as shown in Fig. 2, when there are two, the distance between them being from 10 to 20 feet. The distance apart does not seem to be a matter of much importance; in pits such as that shown in Fig. 3 the same kind of tubes are put down within a few feet of each other.

These crude looking pumps are much more effective and economical in their working than would be supposed. The pump rods are of wood, their section being equal to half the area of the working barrel; consequently in both the up and the down stroke the delivery is equal to half the capacity of the barrel. In effect therefore the pumps are double-acting, with only one set of valves, and the load is in a measure equalised between the up and down strokes; they correspond with the ordinary bucket-and-plunger arrangement common in mining districts. The working barrel is either a brass casting bored out, or made of drawn brass tube. The foot-valve at bottom is inserted from the top, and can be drawn out and replaced

without trouble, after the pump-rod and bucket-valve have been removed.

The two tube-wells of 10 inches diameter at San José, already mentioned, were put down by contract for 5*s.* per foot for the first 100 feet, including everything. For a second 100 feet the cost per foot would be something more, not exceeding 50 per cent. extra and generally less, according to the nature of the ground to be sunk through. Wells from 7 to 8 inches diameter, and not exceeding 150 feet deep, cost from 4*s.* to 6*s.* per foot, including galvanised tubing inserted ready for use. Much depends of course on the nature of the ground; and if boulders are met with, the whole work may be lost. It is not easy to withdraw the tubes, and in case of obstruction they are generally abandoned.

A serious impediment to the use of these pumps is the wear of their valves or leathers, which are soon destroyed by sand and gravel. To renew them, the pump-rods of 50 to 100 feet length have first to be removed by drawing them up and disconnecting the sections one at a time. As the rods are long, heavy, and inconvenient to handle, half a day's time of two men may be required to replace a leather which will not last twenty-four hours after it is inserted. Accordingly for pumping from the sand and gravel strata the author is of opinion that no machinery which involves close-fitting pistons or sliding joints of any kind exposed to the water can ever succeed in California.

Centrifugal Pumps.—The destruction of pistons by the sand and gravel has led to the adoption of centrifugal pumps. In these, with their constant and rapid flow, the sound of the gravel striking against the elbows and sides of the pipes can be heard distinctly. A pile of gravel and coarse sand soon accumulates wherever the speed of the discharged water is slow enough to allow of precipitation; and the wonder is what supplies the displacement thus caused at the bottom of the wells. Elsewhere it has not been common to recommend centrifugal pumps for high lifts, and they have been considered less economical than piston pumps; but the opinions hitherto entertained regarding them have been much modified by the experience of their working in California. A head of 100 feet

however, for a centrifugal pump to work against, is a very different thing from a head of only 10 feet; the impact or mechanical push of the vanes, which is a very important factor, diminishes as the head increases, and as the speed of the tips of the vanes exceeds that of the water in the volute casing. When the head exceeds 40 feet, efficiency declines rapidly, but not to such an extent as to outweigh the great economic advantages of centrifugal pumps for heads up to 100 feet or even more.

For lifting water from the gravel strata in California, four kinds of centrifugal pumps have been employed, namely:—firstly, the common make with open vanes revolving in a plain volute casing; secondly, wheels with shielded or encased vanes, the water being drawn in at the centre and discharged from the circumference; thirdly, compound pumps with two or more wheels acting in succession upon the water during its passage through the pump; and fourthly, balanced pumps receiving the water at one side, whence it is deflected in an easy curve to the circumference by a conical disc on which are formed the vanes. These various forms of the centrifugal pump may be regarded as phases of development, adapted in some cases for particular objects, but generally reverting from encased vanes, compound or double wheels, and other features, back to the original simple form of the first pumps in use prior to 1820. The wheels with encased vanes, for example, have been a feature of the earlier practice with most prominent makers. These wheels were made in America as early as 1831, mainly with the object of partly avoiding side thrust when a single inlet was employed.

Centrifugal Pumps with Open Vanes.—These were at first employed for lifts up to 30 feet, and were usually arranged as shown in Fig. 3, Plate 1, at the bottom of rectangular pits sunk to the depth required for bringing the pumps within suction distance of the water. The pits have often to be sunk 50 feet or more below the surface, and are usually 10 to 12 feet long and 4 to 6 feet wide. The sides are lined with planks of redwood (*sequoia*), which is very durable under exposure in such situations. Two or more tube-wells T are sunk from 50 to 150 feet below the bottom of the pit; and in them are placed

suction pipes S, connected by bends at top to the upper side of the horizontal pump casing, as shown in the drawing. This mode of connection is adopted simply for convenience in the present case, in which there is no upward thrust; but in some cases for a different purpose, as will be further described presently. The pump P is driven by a vertical shaft, which is mounted in pivoted bearings B of the peculiar kind shown in Figs. 4 and 5, Plate 2, each having a supporting collar for carrying the weight of the shaft and pump wheel. The compression couplings C, shown in Figs. 6 and 7, for connecting the several lengths of which the shaft is made up, are so constructed as to be almost instantly loosened or removed. These couplings were introduced in England a short time ago by the writer, and have given evidence of superiority over the more intricate modifications that have preceded them.

The uptake or rising main U from the pump, Fig. 3, Plate 1, is of galvanised iron, and preferably two to three times as large in area as the delivery nozzle on the pump. The pumps are charged in several ways, always from the top of the pit. In Fig. 3 is shown a steam ejector at E, with a small pipe running down to the pump. Air pumps are sometimes used. Charging with water is out of the question, because foot-valves are no longer employed; it was found that the rapidly entering water, loaded with sand and gravel, cut away the valves like the sand-blast process; and there is no room in the well, as there is above, for making flap-valves that swing clear of the current.

For some of the earliest pumps horizontal driving shafts were employed, with bands extending down the pit from a shaft at top to the pump at bottom; but the weight of the bands, the danger to any one descending the pit, and the delay caused by breaking, rendered that plan undesirable, and it has given way to vertical driving shafts. One of the first experiments in deep pumping with a centrifugal pump was made in a case where the water stood at 70 feet below the surface; and when it had become lowered by pumping, the lift was 74 feet. The pump was a compound one, driven at 900 revolutions a minute, raising 10,000 gallons an hour. The pit was only 3½ feet square, and the pump was fixed at 60 feet below the surface. A band

passing down the pit was employed for driving; but the difficulties attending its use were such as to direct attention to other and safer methods of transmitting power in deep pits.

Centrifugal Pumps with Shrouded or Encased Vanes.—Nearly all makers of centrifugal pumps in California and elsewhere have at first followed Sir Henry Bessemer's plan of more than thirty years ago (Proceedings 1852, Plate 69, Figs. 9 and 10), employing a shrouded wheel, in which the sides of the vanes V are attached to two enclosing discs that revolve with them, as shown in Fig. 10, Plate 3, and in the plan of the wheel, Fig. 12. The difference is very great between a wheel or runner constructed in this manner with closed sides, and an open wheel without enclosing discs attached to the vanes. With the shrouded wheel a water-tight joint must be maintained all round the inlet orifice: otherwise the water would only circulate through the pump, passing from the circumference back to the inlet. Such leakage is increased by the pressure, which at all points on the sides of the wheels is the same as in the discharge pipe or at the discharge orifices of the wheels. The skin friction of the water is no less with a shrouded wheel; the water, instead of being driven round in contact with the sides of the stationary casing, flows through the wheels as it does through the pipes, without any greater skin friction in passing through the wheel than for an equal distance in the pipes; but on the other hand there is an equal skin friction of the outside of the wheel itself. The latter has been found to be diminished by having a considerable thickness of water intervening between the outside of the revolving wheel and the inside of the stationary casing. In the pump shown in Plate 3 there is only a very narrow clearance space at the sides of the wheel; but here unusual care has been taken in construction, the wheel being turned and made perfectly true after being keyed on the spindle. The resistance greatly increases if the wheels are not perfectly true; but up to the present time the data respecting friction in such cases are meagre. Experiments now being made in the University of California it is hoped will before long afford useful facts respecting the friction of submerged bodies revolving at high speed.

As the water enters through one side only of the wheel, it causes a thrust in that direction, which is equivalent not to the force of suction only, as is generally supposed, but to the area of the inlet multiplied by the maximum pressure of the discharge. The pump being inverted, with the suction inlet at the top, the entering water flows downwards, and the reactive force is consequently upwards. The upward thrust, which in most cases would be objectionable, is here turned to practical account for supporting the weight of the vertical driving shaft and the pump-wheel. The plan of inverting the pump so that the suction enters at the top was introduced in California by the writer in the latter part of 1883; and was then believed to be of great importance, because of the difficulty of supporting the vertical driving shafts by other means in the deeper pits. In the case of one pump, completed in 1886, the weight of the shaft and its attachments was nearly 2,000 lbs. The shaft was of steel, $2\frac{1}{4}$ inches diameter, and ran at 600 revolutions a minute. The upward thrust was sufficient to carry this shaft, together with some additional weight which was found necessary. The lift was 90 feet, inlet of pump 10 inches diameter, throat of discharge 5 inches diameter, uptake pipe 10 inches diameter. This problem of thrust upon enclosed wheels taking water at one side is an intricate one. If the rear side of the wheel is exposed, as is common, to a pressure equal to the discharge, the thrust, as already stated, is equal to the inlet area multiplied by the discharge pressure. If the wheel is shrouded on one side only, the thrust will be equal to the whole area of the wheel multiplied by the discharge pressure.

At starting there is of course no upward thrust until the pump is charged. Provision is therefore made at C, Fig. 10, Plate 3, for carrying the shaft on collars, which are already required for steadying the revolving wheel laterally in the pump casing, and are so arranged as to support the shaft vertically for a short time, unassisted by the water thrust. The collars are screwed upon the shaft, and several thin washers of steel are inserted between them and the seat which carries them. They run in a pool of oil; or rather oil and water, because there is generally a small pipe leading a little water back from the discharge pipe D to the thrust box C. The joint thus

formed seals the pump, taking the place of a packing gland. The suction pipes SS in Fig. 10 are shown as they are commonly arranged, for branches leading in from right and left; their large area is intended to be equal to that of a number of branch pipes, and to keep the flow in all at a uniform rate as nearly as possible.

Compound Centrifugal Pumps.—Two of the main problems to be dealt with in applying centrifugal pumps to high lifts are how far the impact or mechanical push of the vanes may be disregarded as a factor in the pump's duty, and how the bearings and driving gearing may be maintained in proper order at the high speed required. Practically the speed at which the pump should be driven increases as the square of the height of lift. For example, the circumferential speed of the revolving wheel for a lift of 60 feet will be at least six times as fast as the discharge column should flow; while for a head of 80 feet the circumferential speed for the same flow would have to be more than ten times that of the discharge current. It is therefore seen in how rapidly increasing a degree the revolving wheel must overrun the flow as the lift increases; and how rapidly the effect due to impact or mechanical push of the vanes falls off, as the velocity of the wheel increases. For lower lifts the extent of overrunning diminishes in the same degree, and the gain by impact is increased accordingly. It is easy to attain high efficiency in centrifugal pumps working against a low head; but it is a difficult matter to arrange such pumps suitable for working in the deep pits in California, against a pressure of 43 lbs. per square inch or 100 feet total lift, and to secure results that are satisfactory. Thus far it has not been possible to make experiments for determining definitely the efficiency attained in these high lifts. From such observations as have been made it would seem that from 35 to 45 per cent. of the indicated power has been realised in water raised.

Some of the pits at first made were too narrow to admit pumps with volute casing and with a single wheel large enough to attain the required speed. In such cases the pumps have been compounded, as shown in Plate 4, so as to reduce the speed of rotation and diminish the size of the wheels and casing. In the compound

pump here shown with two revolving wheels R, the main casing is made in five parts, consisting of three hoops or rings and two intervening diaphragm plates, all secured together by external bolts. The driving shaft from the top of the pit is coupled to the pump spindle at C. A charging pipe P is carried down from the top of the pit, as in the case of Fig. 3 previously described. The foot of the delivery main M is surrounded by an annular air-vessel A. The water is drawn by suction into the top chamber T, whence it passes downwards through the two wheels or runners R, and out through the discharge chamber D, the delivery valve V, and the rising main M.

The two shrouded wheels have each five curved vanes, as shown in the plan, Fig. 16, Plate 4. The exact shape of the curves is believed by the writer to be a matter of very little importance in practice; and the number of the vanes, whether two or six, does not make much difference in a high-speed pump. Curved throat-pieces and tangential tips to the vanes are found in such cases to be of practical value so far only as they tend to obviate friction and consequent slight loss of power. The diaphragm above the upper runner is a plain flat plate; but the intermediate diaphragm between the two runners is made with fixed guide-blades on its upper side, for leading the water back from the circumference of the upper wheel to the central inlet into the lower. Besides the double inlet at SS, two more inlet orifices are provided in the top cover at I I, Fig. 15, for convenience of attaching additional suction pipes in different cases; but it is not often that all four inlets are required. The delivery valve V is arranged to swing clear of the ascending column of water; the area of passage is here contracted, and determines the pump's capacity. In all other parts the area of passage is made much larger. Except for avoiding concussion from the water in stopping the pump, the air-vessel A may seem superfluous in a continuously acting pump; but it is not so, and air-vessels are now applied by the writer in all cases for deep pumping. The seat of the delivery valve V is raised so as to leave an annular space all round it, for catching any gravel deposited in the valve chamber; this space is commonly made much larger than shown in the drawing.

The bottom bearing of the pump spindle at B, Fig. 13, is simply a hole bored in the base plate. There is no strain upon it when the wheels are carefully balanced. It is of course exposed to sand and gravel, but these do not seem to have much effect upon bearings of steel running in cast iron; either the sand is at once pulverised and washed out, or in some other way attrition is prevented. Similarly the throats of the inlet orifices in the revolving wheels do not seem to wear after they have worn themselves out of contact.

Triple Compound Centrifugal Pump.—In Fig. 17, Plate 5, is shown a vertical section of a proposed triple compound pump, which however was not carried out because of the low efficiency that such an arrangement must entail. The suction pipe S is here connected with the bottom of the pump casing, and the water entering at A ascends through an inlet orifice in the underside of the bottom runner, from which it is delivered to the top of the pump, and thence passes downwards through the two upper runners, and from the lower of them to the delivery pipe D. Two of the three wheels balance each other in vertical thrust; and the upward thrust of the third would be sufficient to support the steel driving shaft of $2\frac{1}{2}$ inches diameter, together with all its mountings, the whole weighing 1,800 to 2,000 lbs.

In one instance the working of a centrifugal pump has been interfered with by the liberation of carbonic acid gas in the suction pipe, owing to the vacuum of 6 or 8 lbs. per square inch below the atmosphere. The presence of such gas in artesian water had previously been suspected, because of a constant accumulation of air, as it was supposed to be by those in charge of the pumps. The difficulty is easily overcome by avoiding pockets or catchment places on the suction side.

Balanced Pump with single lateral inlet.—In Plate 6 is shown the construction now adopted by the author for pumps with a single inlet at one side, a form most suitable for the requirements of the Pacific Coast, and essential in many cases. The drawing shows a

pump of 12 inches bore arranged for a head of 30 feet. The wheel consists of a curved disc D, shaped so as to deflect the water gradually from the centre to the circumference. On the face of the disc are formed the vanes U and V of unequal area. On the back of the disc are also vanes N. Holes C are made through the disc, so that any water passing over the circumference may circulate in this way. An equal or nearly equal centrifugal action is thus set up on each side of the disc, and there is no axial thrust, the pump being balanced in the same way as though there were double inlets, one at each side. In this arrangement the suction pipe is easily removed, and can be hoisted vertically clear of the pump. The water passages are also more free, and of large area until the disc is reached. In order to guard the spindle bearing from sand and grit, the packing is placed at P inside the main bearing B, which acts also as a gland for compressing the packing. This arrangement is now employed in all the various modifications of centrifugal pumps from the author's designs, and in working permits no leak of either air or water; and the packing seldom needs renewal. The pumps are characterised by great steadiness of running, and an absence of the pulsation or jar common with free or open vanes or with shrouded wheels. Such jar is often caused by an obtuse or imperfectly formed throat-piece at T, especially with shrouded wheels, the radial flow being interrupted at that point.

A matter perhaps of some interest is the method employed of giving the proportions for different sizes of pumps of this class; it is applicable also to various other kinds of mechanical engineering work. The dimensions of all the various parts are arranged in a table, which includes one class of pumps from 2 inches to 10 inches; and this table takes the place of drawings for each size, especially in constructing patterns. In the present instance the table gives eighty dimensions for each of nine different sizes of pump. The several dimensions cannot be assumed from graduated scales, but must be the result of accurate drawings for nearly all sizes. This plan has been applied to various kinds of work in the author's practice, and is believed to be of great value in any case where system and uniformity are possible. The dimensions can be easily changed for special

machines, and determined by approximation, without the usual difficulty of working out a wholly new design.

Improved Pit Pumps.—In Fig. 21, Plate 7, is shown the common arrangement of what are called pit pumps in California. When the water rises in the wells within suction distance of the surface, horizontal pumps similar to that shown in Plate 6 are employed; but when this distance exceeds 20 feet, rectangular pits are sunk, from 10 to 60 feet deep, as previously described and as shown in Fig. 21. Two or more tube-wells T are sunk from 50 to 150 feet below the bottom of the pit; and in these are inserted the suction pipes S, leading to the suction box A on which the pump P is mounted. The driving shaft D is supported in thrust boxes BB, and when of several lengths is connected by clamp couplings, as shown in Figs. 8 and 9, Plate 2, the bolts L passing through the ends of the shaft D, so that the couplings may not drop down if they should come loose. The pump being balanced, there is no thrust except that caused by the weight of the spindle and wheel. This is taken up in the thrust box E, which has an annular oil-chamber, and collars that perform the double office of supporting the spindle and sealing the joint to prevent the entrance of air, thus taking the place of the common packing gland. The air-vessel H and check-valve V are shown in enlarged section in Fig. 22. The valve V is so arranged that when open it stands clear of the water-current, as indicated by the dotted lines; otherwise the facing is soon cut away by the sand and gravel, which act like the sand-blast. Foot-valves cannot be employed in the suction pipes, because in most cases there is no room in wells for a case large enough to allow of the valve opening fully. The valve seat at K is raised to avoid the valve being fouled with gravel. The external case H is made rectangular in plan, with the two-fold object of giving it elasticity, so that it shall not be broken by water-shock in stopping, if the air cushion should fail, and also of allowing the valve to open fully. The uptake pipe U is usually made of sheet-iron coated with zinc and soldered at all joints. The area of these pipes is an important matter, and does not seem to conform with the usual rules and computations respecting resistance.

It is found expedient to have their area at least four times that of the pump discharge, when the head exceeds 50 feet. A charging pipe N is carried up to the surface, where an air-pump or steam-ejector is employed to exhaust the air and fill the pump P.

Among the principal objects aimed at in the present pumps are—the greatest possible simplicity; easy separation into parts, so that the machinery can be raised out of the pits or lowered into them without tackle; access to all interior parts; and the highest efficiency possible under the circumstances. The circumferential speed of the pump-wheels in feet per minute being approximately 500 times the square root of the head in feet, wheels of 24 to 30 inches diameter can be used for heads up to 100 feet without the speed of the shafts exceeding the rules of safe practice.

In 1884 the author designed compound or double-wheel pumps for use in pits, two wheels being employed as proposed many years ago by Mr. Gwynne and also by continental makers; but with the difference that the water was drawn into the top of the pump and discharged from the bottom, as shown in Plate 4. The wheels being unbalanced, and subject to a thrust equal to the area of their inlet multiplied by the head, by inverting the pump this force was employed to support the weight of the revolving parts. This seemed a good method of evading the thrust; but the least change of speed destroyed the equilibrium, so that the thrust was first up and then down; moreover the upward thrust did not begin until the pump was acting, and consequently in starting, or in case of the pump drawing gas so that the water failed, the whole weight of the running parts was thrown on the pump bearings. A number of these pumps have been made, and have performed very well, with the exception of the above difficulties and a low efficiency. The efficiency was reduced by the discharge from the wheels being radial and the impact being of course lost. The effect of the mechanical push of the vanes is no doubt greatest when the relative speed of the tips of the vanes and of the water at the same point is approximately as two to one; and it diminishes as this ratio is departed from in either direction. This indicates for high heads the expediency of a contracted volute or casing, so as to give the water as great a

velocity as possible there until the discharge is reached. Some recent experiments confirm this view.

In Plate 3 is shown a horizontal pump for shallow pits, designed by the author in 1884, and applied in a number of cases for lifts from 30 to 50 feet. It is also an example of balancing the weight of the driving shaft by the upward thrust of the wheel, the water being taken in at the top. The wheel is of the shrouded or encased kind with six vanes, discharging into a volute casing. These pumps were at first arranged without a packing gland for the spindle; but the irregularity of the upward thrust and the consequent lifting of the shaft prevented effective sealing by the thrust collars at C. A difficulty sometimes experienced with these pumps receiving the water at the top is the accumulation of carbonic acid gas given off by the artesian well water, especially from deep wells. In the pumps arranged as in Fig. 21, Plate 7, this does not occur, because the gas is free to ascend and pass out with the discharge water.

Low-lift Centrifugal Pumps for land reclamation and irrigation.—As the Sacramento and San Joaquin rivers approach the ocean, the sedimentary plains bordering upon them sink below the level of the winter and spring floods, and hundreds of square miles become covered with water from one to ten feet deep. These plains are called tule lands, from a kind of soft reed of that name which covers the whole surface where water stands. When drained of water and cleared of the tule growth, the soil is a bed of vegetable compost of such surprising fertility and strength that crop after crop can be grown in the same year. It is mainly on these tule lands that are produced those prodigious crops of wheat, barley, potatoes, &c., which have rendered California famous in agriculture. These fertile lands, lying near San Francisco, and reached by water, rail, and roads, are of great value, and their reclamation has been the object of costly and extensive efforts. The work has been attended with great difficulty, and the larger part of the area once drained has subsequently been lost again, in consequence of the fluctuations of the rivers being so uncertain, and the period of exact observation having not yet been long enough for determining the levels of high

floods. Moreover placer mining has sent down silt enough to change nearly all the levels during the past twenty years. The embankments when made of peat have not weight enough to resist the pressure of the water; and being buoyant are sometimes floated away bodily. They are so porous that the percolation is enough to require pumping machinery in most cases; besides which, the rainfall in winter and spring has to be pumped out when the rivers are higher than the lands. The uncertainty as to the quantity of water to be raised, the absence of permanent foundations, and the speculative nature of the attempts to reclaim the land, require machinery not merely of a cheaper kind than elsewhere, but also of quite a different character from that employed in other parts of the world, where land drainage is mostly performed at central pumping stations constructed for a definite and permanent duty. The tule lands are divided into districts, for each of which there is an engineer by whom all plans and estimates for pumping machinery are closely examined; and a guarantee of efficiency is required.

Besides the reclamation of the tule lands, there is also the nearly analogous duty of pumping from rivers to irrigate what are called the bench lands, lying from 15 to 30 feet above the water level. The limit of the height to which water can profitably be raised by machinery for ordinary crops at the present price of fuel and cost of machinery may be set down at 25 to 35 feet. Most of the pumps now in use are of small size, such as may be driven by threshing engines of 25 to 35 I.H.P., and are of the types already described.

In Fig. 23, Plate 8, is shown a reclamation pump of the usual construction, which is mounted on a framing made of Oregon pine. This is a hard stiff kind of timber, almost as strong as ash, straight grained and without knots, of which beams can readily be obtained 50 feet long and 24 × 12 inches section. For the smaller pumps, iron bed-plates are employed; and also for the larger, wherever the extra cost is not objected to; but the timber frames answer very well, provided the machinery is so arranged that its working shall not be interfered with by such flexure as the timber framing is liable to. The centrifugal pump is arranged with its spindle horizontal; and in order to avoid end thrust the wheel is made with open vanes. The

interior of the casing is turned smooth; and the wheel is also carefully turned after having been fixed on its spindle. The engine E has two single-acting cylinders, of which the diameter is usually equal to two-thirds that of the discharge pipe D from the pump, when the total lift is not to exceed 20 feet. The driving shaft is of steel, and is connected with the engine by a compression coupling C, Figs. 6 and 7, Plate 2, the same as previously described. The bearing B next the pump is mounted on a planed iron seating, so that it can be slid back when the pump gland requires packing. By thus supporting the driving shaft close up to the pump, no bearing is required on the suction side of the pump, which would be objectionable on account of the obstruction it would offer to tule roots, weeds, straw, and other rubbish that finds its way into the pump.

All the parts have to be arranged for allowing of ready access to the interior of the pump and pipes. The suction pipe S is slung by a chain N, so that it can be lifted away from the pump in case of the foot-valve at F becoming choked. The inlet nozzle of the pump casing can be cleared from ordinary obstructions by removing the hand-plate at H. The two side-plates of the pump casing are easily removed. Whenever the wheel becomes clogged with tule roots, the suction pipe S and the plate on the same side are loosened and swung aside; the coupling C is also loosened, and the wheel can then be drawn out at the suction side to be cleared. The time of the whole operation need not exceed ten minutes.

The pump here shown, Fig. 23, Plate 8, is of a semi-portable character, and adapted to most cases, but not to all. When the head varies on the delivery side, as it does sometimes from 1 foot to 14 feet, it is evident that a pump arranged in this manner would not answer. The pump and engine must of course stand above the water-level, which varies both inside and outside the embankment. There is no means of working economically against a low head, except by submerging the pump wheels. The height of the suction lift must be more than the variation of the water inside the embankment. Consequently when the water is low on both sides of the embankment, as much as two-thirds of the work may be lost, unless the syphon

action of the discharge pipe can be relied upon. A bottom discharge for the pump would remedy this difficulty in a measure; but it would involve the addition of an air-tight sluice-valve in the discharge for starting the pump, and also a pneumatic or steam charging apparatus. The syphon action of the discharge pipe soon ceases, especially when the pipe is large, unless there is some means of continuously exhausting the air given off by the agitation of the water in the pump. To connect the discharge pipe with a condenser, or to employ other means of exhausting the liberated air, introduces complication not compatible with the attendance commonly received by such pumps on the Pacific Coast.

Submerged Pumps.—In Fig. 18, Plate 5, is shown a vertical pump of the Whitelaw type, of which several have been constructed on the Pacific Coast from the writer's designs; it is one of the cheapest arrangements, and places the machinery well above the water, excepting only the pump-wheel which is submerged. The engine and boiler are placed on the top of the embankment M, and are generally raised one to two feet above the ground; the embankment itself is in most cases wide enough for a roadway on the top, whereby fuel can be hauled or access obtained to the works when the whole country is flooded. The pump casing P is a vertical cylinder, having a suction nozzle at the bottom, and a flange at the top by which it can be suspended from the bottom of the trough T. The pump spindle is supported in three bearings as shown, and is driven by a band from the engine E. A pair of bevil wheels are sometimes employed at the top of the spindle, so as to avoid twisting the band. The wheel or runner R is curved upwards, so that the tips of the vanes terminate parallel with the sides of the pump casing. Inside the casing is inserted a central sheet-iron cone C; and the current of discharge water, ascending through the widening annular space between the cone and the cylindrical casing, loses its velocity gradually as the area of passage enlarges; while at the same time the whirling motion with which it quitted the wheel is checked by means of curved blades B fixed on the outside of the cone, whereby the current is deflected upwards.

Since centrifugal force acts at right-angles to the axis of rotation, it is evident that the water has to undergo deflection through one more right-angle in a pump of this kind, with curved runner discharging parallel to the axis, than when the discharge is at right-angles to the axis. But although the efficiency may thereby be impaired to the extent of as much as 10 per cent., this is often of less importance than the countervailing advantages gained with submerged pumps. There is no charging to be done, no valves, and no pipes. Tule roots and other obstructions pass freely through the runner, and are thrown out against the pump casing, where they are soon worn away. The pump shown in Fig. 18 is for raising 400,000 gallons an hour, the cylindrical casing being 40 inches diameter, and the engine capable of developing 35 H.P. Similar pumps have been erected on the San Joaquin and the Colorado river, and have raised 660,000 gallons an hour.

Nearly forty years ago Mr. Whitelaw's experiments at Johnstone, near Glasgow, demonstrated that a high efficiency could be attained with pumps arranged in this manner. The only impediment is in utilising the energy of the water after it leaves the wheel R. If the velocity is destroyed by impinging against the body of water in the uptake P, the efficiency for low heads will not exceed 40 per cent. The pump shown was much improved by inserting above the wheel R the cone C having curved deflecting blades B, which change the motion of the water from a horizontal to a vertical direction. With careful attention to the various conditions accompanying the action of centrifugal pumps, this arrangement has much to recommend it, especially in economy of first cost. In the Louisiana district about the mouth of the Mississippi river, pumps of this kind are extensively employed for low lifts, the action being analogous to that of a turbine water-wheel inverted, and centrifugal effect being almost disregarded.

Bulkhead Pumps.—In Fig. 25, Plate 9, is shown a plan of a pair of centrifugal pumps arranged for driving the water through a bulkhead against a head varying from nothing to 10 feet. The

pumps are submerged to a sufficient depth to require no charging, and consequently no valves are necessary. The area of the two discharge nozzles is 150 square inches each, and the quantity of water delivered is 500,000 to 800,000 gallons an hour. This arrangement is the least expensive that can be adopted for land drainage or irrigation; it was suggested by a Dutch engineer who had erected similar works in Java, and has been found in every way satisfactory. The embankment is cut through, and a strong timber bulkhead A is erected across the gap. The pumps P P are placed immediately behind the bulkhead, with their discharge nozzles projecting through it. Flap valves opening outwards are hung over the discharge nozzles at D, to prevent back flow through the pumps when not working; in dry seasons they are sometimes opened for letting water flow through for irrigation. The vertical pump-spindles are driven by bevil gearing from a horizontal shaft. The engine E is single-acting, with two cylinders of 10 inches diameter, and its speed is 300 revolutions per minute. The machinery shown in Fig. 25 was erected during 1885, on the Sacramento river, 75 miles from San Francisco, for draining tule lands.

The average head in this case being only from 3 to 5 feet, it was considered that the water could be driven more by direct push than by centrifugal force. The pumps were constructed accordingly with smooth iron vanes, bolted to a square extension on the pump spindle, as shown in Fig. 26, Plate 9. The throats of the suction inlets were made very sharp, and brought in as close as possible to the inner tips of the vanes. In the writer's opinion the effect would have been much the same, or perhaps even better, if the volute casing had been replaced by the ordinary concentric casing. When a good turbine water-wheel will realise a duty of 70 to 80 per cent. by the direct pressure of the water, there seems no reason why a centrifugal pump, considered as a turbine-wheel acting in the reverse manner, should not utilise in some near proportion the power applied to it for moving and raising water. The writer is not aware whether any investigations have been made in this direction; but there appears to him to be a close analogy between the two cases, at least for low heads.

Pumps driven by Bands.—In Fig. 27, Plate 9, is shown an arrangement for raising 900,000 gallons an hour by means of two centrifugal pumps driven by bands. The two discharge nozzles from the pumps are each 115 square inches area. The pumps have open wheels, and double suction-pipes S, one on each side, not joined; each pipe has a foot-valve of 100 square inches area. The suction-pipes themselves serve as the supports for the pumps, being made strong and with large flanges to rest on the timber framing. The sump U is 6 feet deep, and the suction-pipes dip into it to different depths, so that when the water supply falls short the higher pump will run empty or be disconnected, leaving the lower only to continue working.

The discharge pipe D carried through the embankment is 30 inches bore, and is set with slope enough to let the water run down it from the pumps when the head at the discharge outlet O is not too high. The engine E is placed level with the top of the embankment, 15 feet above the pump floor. The whole of the machinery is mounted on wooden framing, being on treacherous ground; it was erected during the winter, when no other foundation was possible, for the purpose of draining the leakage and rainfall from 8000 acres of land, surrounded by embankments 15 miles long; the estate is on the Sacramento river, and is one of the best maintained in the valley. The embankments are of a superior character, being for the most part made of clay or loaded with clay; they sink however, and have continually to be raised and strengthened. This plant has since been increased to a capacity of 2,400,000 gallons an hour, by the addition of pumps of 30 inches bore, driven by a directly connected engine.

Single-acting Engines.—For pumps directly geared to engines, the practice differs somewhat from that of English makers; but is much in advance of the methods employed in the Eastern States, unless it be in the case of one firm there, who have copied Messrs. Gwynne's pumps and drive them with pairs of single-acting engines. The author at first employed single-acting engines, as shown in

Fig. 28, Plate 10. These are in some respects well suited for driving centrifugal pumps where permanent foundations are wanting, inasmuch as they are wholly self-contained, work at high speed with reasonable economy, and occupy but little space. As the thrust on the connections and bearings is in one direction only, there is no compensation to look after. There are no glands to pack, except that of the valve-spindle, and scarcely any oiling to do. In Fig. 28 is shown a longitudinal section through one of these engines, and in Fig. 29 an end elevation. The valves are of the oscillating cylindrical kind, the steam entering at S round the outside of the valve V, and exhausting through its interior. The connecting-rods are of brass, made as light as possible. The crank shaft is of steel, with cranks opposite, and with counterbalances bolted on at C. The valve-gear G is of the simplest construction, consisting merely of an overhung crank and connecting link; the eccentricity of the crank can be readily adjusted for regulating the lead of the valve, or reversed for running the other way. Automatic gear for controlling the speed by the cut-off is sometimes applied; but for regular duty, like pumping, the throttle-valve adjusted by hand is quite as good, and is better understood by attendants. The crank chamber M is partially filled with a bath of water and oil, which is splashed by the cranks into all the bearings and also into the cylinders; no other oiling is required, except of the valve-link, which is made hollow so as to be oiled at both ends while in motion. The cylinders are surrounded by a rectangular casing which serves as an air-jacket, so that but little heat is lost by radiation.

The objections to this class of engines are their dimensions in the direction of the crank-shaft, a want of steam economy, and the low duty consequent upon the compression at the top of the upstroke, required to keep the bearings in contact and to avoid knocking. The difficulties that have been met with during the past ten or twelve years in maturing these single-acting engines are considered by the writer to lie, not in the principle or mode of working, but in providing a suitable connection for transmitting the power from the pistons to the cranks on the driving shaft.

Differential or Compound Engines.—In the author's later practice the engines adopted are of the differential or compound type, as shown in Fig. 30, Plate 10, embodying nearly all the advantages enumerated in favour of the single-acting engine, but in smaller space and more simple. The steam is admitted first into the annular space A surrounding the trunk T, and after acting in the upstroke underneath the piston P is expanded upon the top in the downstroke, acting then on the difference of area between the two sides of the piston, and expanding three times or more. The engines are made without stuffing-boxes except for the valve-stems; and oiling is performed by enclosing the parts, as in the single-acting engines. In this way a good expansion is attained with a single and simple slide-valve; and the engine is reduced to the fewest and simplest parts possible. In Fig. 24, Plate 8, is shown one of these engines connected with a pump for low heads not exceeding 15 feet.

Hydraulic Rams.—Owing to the extensive use of small hydraulic rams on the Pacific Coast, some experiments were commenced at the beginning of last year 1887 by the author in conjunction with Messrs. W. T. Garratt and Co., engineers of San Francisco, in order to see whether larger machines of the kind could be constructed for meeting the requirements of raising water from the mountain streams. As yet these experiments are by no means completed; but the author believes some of the constructive features are of sufficient interest to warrant their being appended to the present paper. The various phenomena that arise in employing the impact of water in hydraulic rams are such as to render the matter one of experiment, unless in cases where the intermissions or valve-movements are controlled by independent machinery, that is by some power independent of the flow or issue of the water passing through the ram. The latter is unquestionably the correct method, if the supplemental mechanism can be made durable and reliable, as no doubt it can.

The first experiments made were with small rams having inlet pipes from 2 to 3 inches diameter, as shown in Fig. 31, Plate 11, in which I is the inlet pipe and D the discharge pipe; C is the check or

foot-valve, and A the air vessel; and V and E are the escape valves fixed on the same stem. A plan of the top of the lower valve E is shown in Fig. 32. The two valves V and E being nearly balanced, the difference of their areas constitutes the measure of the upward or closing force, which is of course much less than in the case of a single valve. The valves fall by their weight in the usual manner; and are raised partly by the stream rushing out round the upper valve V, but mainly by the upward pressure of the issuing current against the curved shield S fixed on the valve stem.

In working it was found that accurate adjustment was required to suit the head or fall of the driving water; and also that the shock was too great for the safety of large rams. The method was therefore changed to that shown in Fig. 33, Plate 11, in which the two escape valves V and E are arranged to pass up freely through their seats, and are stopped by an air cushion at the top. The waste water nearly all escapes at the upper valve V, small outlets only being provided in the lower valve E for permitting sand to escape if any should be carried into the machine. The closing is effected, as before, mainly by the upward pressure of the issuing stream against the curved shield S. When the valves are shot upward in closing, the shield enters the air chamber above it, in which it fits as a piston, and the momentum is thereby checked without the least shock. An air cock is inserted in the top of the air chamber at L, for regulating the amount of resistance offered by the air cushion. Additional weight if required for opening the valves is added on the top of the valve-stem at K; it is found however that, the higher the delivery head, the less is the weight required, because of the reflux. Snifting valves were at first applied, but seemed unnecessary. Rams arranged in this manner work without noise or jar, and give a high efficiency for forcing four to five times the height of the propelling head, and are suitable in most cases for irrigating purposes; but when the resistance is increased, the elastic blow or percussive impulse of the current is not enough to raise the check-valve C against the increased area caused by its lap.

In Plate 12 is shown another arrangement of hydraulic ram, in which the escape valve is opened by independent mechanism. The

water enters at I, and the waste escapes at the bottom through four holes shown in the sectional plan, Fig. 37. These holes are alternately covered and uncovered by the four wings of the oscillating valve V, which is mounted on a spindle S. The valve is opened by means of the water-wheel W and the tappet motion shown in Figs. 34 and 36. The two tappets coming in contact at each revolution of the water-wheel open the valve to such an extent as may be determined by the adjusting set-screw in the slot at A. As soon as the tappets disengage, the valve is closed by the reaction of the issuing stream against its curved ribs or vanes, as shown in Fig. 37, the motion being arrested by the tail T of the tappet arm, Fig. 36. In this manner the motions of the waste valve V can be controlled at will, and a greater efficiency attained than with the ordinary method of employing the force of the issuing stream for closing the valve by lifting it. Experiments have not yet been made to determine the most effective motion of the valve with respect to the time of closing; but the indications point to variable requirements in this respect, depending on the resistance offered or the height to which the water is being raised. The action of the machines is smooth and regular when the closing motion is not too abrupt.

While unable at present to furnish a more complete description of this class of machines, the author hopes the subject is wide enough to permit of its being again brought before the Institution on a future occasion in a more complete form.

Discussion, 30 *September* 1887.

Professor W. CAWTHORNE UNWIN considered the paper was extremely interesting, because it gave a kind of record of the slow evolution of a particular class of machinery, extending over a long course of years, and no doubt embodied results due to extensive experience: so that the conclusions at which the author had arrived ought to be received with a very considerable amount of respect.

What would most attract the notice of English engineers was the account given of centrifugal pumps, especially of compound centrifugal pumps. These had been proposed a very long time ago, having been described in Morin's book on pumps; but for some reason or other they had never found favour in this country, and comparatively few had been constructed in Europe. But obviously in California they had succeeded; and looking at them from any theoretical point of view, they certainly ought to succeed. He could not conceive why, in many cases where centrifugal pumps were used in this country with moderately high lifts, the pumps had not been made compound. It appeared to him that the whole of the difficulty which arose in adapting the centrifugal pump to a moderately high lift was cleared when the pump was made compound. Perhaps some of the Members might have seen in Manchester the triple compound centrifugal pump designed by Professor Osborne Reynolds, which was working with great success, and he believed with considerable efficiency.

In page 39 of the paper it was stated that after the head reached 40 feet the efficiency of centrifugal pumps fell off rapidly; but he knew of some practical results which would contradict that; and especially from the theoretical point of view he could not conceive why at 40 feet head the efficiency should in any way diminish. The centrifugal pump was simply a reversed turbine; and turbines were being put up on falls not of 40 feet but of 400 feet, and showed the same efficiency at the higher head as at the lower. He did not know of any instrument used by engineers, in the design of which there was sometimes more recklessness of scientific considerations than was seen in the design of centrifugal pumps. Either a

centrifugal pump was put up to work on lifts varying from 0 to 30 or 40 feet; or if the lift were constant, the pump was expected to pump sometimes 1000 gallons an hour and sometimes 10,000. No single machine like a centrifugal pump could possibly be adapted to such great variations of condition, without working for a great part of the time at a low efficiency.

The low efficiency of the centrifugal pump had arisen chiefly from two causes. The first was that the pump was expected to adapt itself to the motor, instead of the motor being adapted to the pump. It was convenient to run an engine at a certain speed suited to the engine itself; and therefore the pump was wanted to run at the speed which suited the engine. The efficiency of the centrifugal pump, like that of the turbine, was very closely connected with the diameter of the pump; and if good efficiency was wanted in centrifugal pumps, they must be made of a diameter which suited the lift. The friction of the pump increased something like as the fifth power of the diameter: whence it was easy to see that the waste of work, which was almost entirely friction in the pump, increased very fast if the pump was made of too large a diameter. The second cause of low efficiency in centrifugal pumps was the absence of proper arrangements for utilising the kinetic energy of the water leaving the pump disc.

A statement made in page 41 of the paper appeared to him to be an error, which, though not very serious, affected the choice of the type of pump. The author there spoke of pumps with encased or shrouded vanes as having been largely used and in many cases abandoned; and the only argument he used against the efficiency of such pumps was that they were liable to have considerable leakage at the joint between the pump and the casing all round the inlet orifice, Fig. 10, Plate 3, because the pressure at that joint was the full pressure due to the head in the discharge pipe. That however was not the fact; for the water between the stationary casing and the pump-wheel was put in rotation by the friction of the outside surface of the revolving pump-wheel. As the consequence of this water being in rotation, the ordinary proportion of pressure or head at the joint round the inlet orifice was only one-fourth what it

(Professor Unwin.)

was at the outer circumference of the wheel; and therefore, although there might be a slight gap at the joint, any leakage at that point he thought was not really a very serious matter.

In regard to the unbalanced axial thrust of the centrifugal pump which received the water on one side (page 42), the way in which that thrust acted was perhaps not at first sight quite intelligible. Within the last week he had received from California an account of some experiments on the amount of this thrust, suggested no doubt by precisely the experience described in the paper; and they so far explained the action of the thrust that he would point out the results to which they led. In some of these pumps, as mentioned in the paper, the whole weight of the pump and gearing was supported by the upward thrust due to fluid pressure in the pump. It had occurred to Professor Hesse to see whether a good footstep might not be made by utilising this thrust; and the attempt had been made in the way shown in Fig. 38, Plate 13. The foot of the vertical shaft S was immersed in a cylindrical casing of water; on the shaft was fixed a perfectly flat circular disc with radial vanes V on its upper face only; while in the bottom of the casing were fixed similar stationary radial vanes B. There was only a little clearance left between these stationary vanes and the plain underside of the revolving disc; and only a little clearance also between the circumference of the disc and the sides of the casing. In the revolution of the shaft the disc with its vanes V acted like a centrifugal pump, producing on the top side of the disc a distribution of downward pressure corresponding with the parabolic surface shown by the area ACWCA, Fig. 39; there was thus a low head or pressure at the centre and a high head or pressure at the circumference. On the underside of the disc the water was kept practically still by the fixed vanes B; and therefore the pressure all over the underside of the disc was practically uniform. This uniform upward pressure on the underside of the disc was that due to the higher head at its circumference on the upper side, and was represented by the rectangle ACCA; and consequently the area contained within the interior of the parabolic curve CWC represented the effective upward thrust which supported the weight of the shaft. At first sight it might be said that this was pretty enough

in theory, but that the friction would be much greater than that of an ordinary footstep. From some singularly careful experiments however, which had been made in California and appeared to be entirely trustworthy, the result arrived at was that for a shaft carrying a weight of 2 or 2½ tons it was possible to design a footstep of this kind of quite moderate dimensions, with a casing of about 18 inches diameter, and with a friction only about half that of an ordinary footstep.

The PRESIDENT then adjourned the discussion to the next meeting. In the meanwhile he would ask Mr. George Richards, who was present, to express the thanks of the Institution to his father for this interesting paper; and to request that, if he had any more information to give, he would kindly send it in time for the continuation of the discussion at the next meeting.

Adjourned Discussion, 2 *February* 1888.

Mr. RICHARDS sent the following reply to the observations made in the discussion at the previous meeting:—

On reflection perhaps Professor Unwin will modify his statement that a centrifugal pump is simply a reversed turbine. Conversant as he is with the laws governing the operation of these two machines, it appears to the author that he must have some other meaning than that they are identical; for centrifugal action, which is the principal factor in the duty of a pump, holds a secondary rank in a turbine, and is often wholly disregarded. His remarks concerning the adaptation of centrifugal pumps to their work are fully confirmed by the author's own observations and experience.

In respect to the objection to wheels with encased vanes, the intention in the paper was to point out that in the case of a single-

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inlet pump such wheels cause an axial thrust equal to the area of the inlet multiplied by the discharge pressure. While Professor Unwin is unquestionably correct in assuming a rotation of the water on the smooth sides of an ordinary shrouded wheel, yet when two or more such wheels are compounded this rotation of the water is not permissible, and has to be prevented by baffling vanes or fixed guide-blades, in order to destroy centrifugal effect and so to permit the water to return to the centre of the second wheel.

The axial thrust of the pump discs is an obscure matter or at least not well understood. A wheel of 24 inches diameter constructed as in Plate 6, but without the vanes on the back, would when working against a head of 40 feet sustain an axial pressure on the back of more than 7,000 lbs. This is opposed by less than one half as much pressure on the front face, leaving what may be called a destructive force pulling the wheel and spindle towards the front or inlet face. The pressure resulting from the impact of the entering water on the front or receiving face, and the gradually increasing pressure on this face from the central inlet to the circumference, are subjects well deserving attention from a scientific point of view: as is also the pressure at different points of the pump casing from the central axis to the circumference, which so far as the author knows is a matter not yet treated upon in any literature on the subject.

Mr. Henry Davey remarked that the triple compound centrifugal pump, illustrated in Fig. 17, Plate 5, appeared to him at first sight to be a very peculiar construction, and one which he did not believe could give a high efficiency. Having had some little experience with centrifugal pumps, though not with compound centrifugal pumps, he imagined from the drawing shown that a compound pump of that construction must possess some radical defects. Such a pump he considered should have a freer vortex or delivery channel round the circumference of the wheel; the casing of the pump was here so near the circumference of the wheel, that there was a very small vortex indeed, and by no means a free one. Moreover the water was baffled, as the author had explained, with the object

of destroying its centrifugal force in leaving the topmost wheel, and of permitting it to go to the centre of the next below. This baffling must detract largely from the efficiency of the pump. Taking the case of an ordinary single centrifugal pump on a vertical spindle, as shown in Fig. 41, Plate 14, the delivery from the pump should be something of the form indicated at D, with a large free vortex in front of the mouth of the pump. Guide vanes had been put into pumps of that construction, with the object of utilising the energy in the vortex for causing the water to ascend; but unless the guide vanes had been very cleverly arranged he believed they had been proved to do more harm than good. This had certainly been the case in two or three pumps of that kind which he had himself put up. Guide vanes were useful in a large centrifugal pump if they were above the free vortex, and if there were not too many of them, say not more than three. In the pump shown in Fig. 17, Plate 5, there appeared to be vanes immediately under the topmost wheel, so that the water which was rotating in front of the mouth of that wheel was at once baffled by the vanes underneath it, and was thereby compelled to take an inward direction towards the suction of the next pump. In this baffling there must be a considerable waste of energy. In the first place there would be a loss of energy from want of a free vortex in front of the mouth of the wheel; and then there would be a further loss of energy from the baffling caused by the fixed vanes.

The collar bearing shown in Fig. 4, Plate 2, did not appear to him to be a good kind of bearing for carrying a heavy weight, such as the heavy vertical spindle of a heavy centrifugal pump. In Fig. 40, Plate 13, was shown a bearing which he believed had been first introduced for centrifugal pumps by Messrs. Easton and Anderson, and which he had used himself when bearings of the kind shown in Fig. 4 had failed. On account of its shape it was called an "onion" bearing; and it consisted of a steel forging, turned to the bulb shape B, with a steel shank passing up through an overhead girder and held by nuts on the top. The spindle S was steadied laterally by the usual bearings to keep it central; but the weight was entirely taken by the gun-metal collar C, which was coupled to the top of the spindle by a flange joint

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with bolts. It would be seen that the upstanding rim upon the top of the collar formed an oil cup above the onion, while the top of the spindle formed an oil cup below : so that the onion ran completely submerged in the oil, which could not possibly get away. This bearing was highly successful, as he could say from experience in several instances where he had applied it, and where an ordinary collar bearing had entirely failed, and a thrust block had also failed. Why this kind of bearing was so successful was not simply because it was submerged in oil, or because the surfaces were larger or of a better shape, but also because it was entirely free, and did not bind the spindle in any way whatever; the spindle was steadied in its own guides, while this suspending bearing was free to take an even bearing. It was not so with the ordinary collar bearing, which had to perform the two functions of supporting the load and also of centering the spindle. There was a freedom in the onion bearing which there was not in the ordinary collar bearing or thrust block; and it was partly due to this freedom he thought that the bearing was so successful. In one case he had taken out a thrust block which had about three times the area of bearing surface that there was in the onion bearing which he had substituted for it; and with the latter he had never had the slightest trouble, whereas the thrust block had always been failing before.

Mr. John G. Mair pointed out that Fig. 17, Plate 5, was stated in the paper to represent merely a proposed triple compound pump, which however had not been made because of the low efficiency that such an arrangement must entail. He desired to thank the author for so generously giving the results of so extensive an experience in low-lift or irrigating pumping machinery. Some of the arrangements of centrifugal pumps described in the paper were undoubtedly good ; but a pump arranged so that the water leaving the disc could continue its rotation in a whirlpool chamber would give the best efficiency. Good examples of this had been given in the paper by the late Mr. David Thomson,* describing the centrifugal pumps of his

* Proceedings of the Institution of Civil Engineers, 1871, vol. xxxii, page 28 and Plate 9.

design which had been made by Messrs. Simpson and Co. for Leith and West Hartlepool docks.

In designing low-lift pumps a question often cropping up was at what height of lift was it better to adopt a centrifugal pump rather than a reciprocating pump. In Fig. 44, Plate 16, where the abscissae represented the height of lift in feet and the ordinates denoted the percentage of efficiency, it was seen from the curve R R that the efficiency of a reciprocating pump fell off very fast indeed as the lift decreased; and it became an important question for engineers what type of pump was most suitable for low lifts. From the experiments made with the centrifugal pumps at Leith and West Hartlepool docks their efficiencies were 70 per cent. on a 20-foot lift and 49 per cent. on a 12-foot lift, as shown by the line C in Fig. 44; but it must be borne in mind that, although a centrifugal pump, if running at a uniform speed, had the advantage of increasing its discharge when the lift was decreased, still its efficiency was at a maximum for that speed only for which it was designed. From the diagram, Fig. 44, it would appear that for pumping water to a less height than about 30 or 35 feet centrifugal pumps had an advantage over reciprocating pumps. An efficiency of over 60 per cent. on 15-foot lifts had generally been obtained by Messrs. J. and H. Gwynne, and of 58 per cent. on a 5 ft. 6 ins. lift, as shown by the line G. But when the lift fell to so low as 5 or 6 feet, it was a question whether scoop wheels, preferably of the Sagebien type, or screw pumps, were not more efficient. Some very large Sagebien wheels put up in Egypt gave an efficiency of 70 per cent., while the large Archimedean screws made on Mr. Wilfrid Airy's system, and also put up in Egypt, gave an efficiency of 80 per cent.; but these had been partly replaced by centrifugal pumps made by Messrs. Farcot of Paris, having vertical spindles driven direct from the crank-shafts, which were reported to give an efficiency of 65 per cent. The scoop wheels used in the Fen districts generally had flat floats, and therefore lifted the water higher than the discharge level; while the Sagebien wheels had curved floats, and were more economical. In a series of notes on scoop wheels by Mr. Wilfrid Airy in "Engineering," vol. ix, 1870, a description was given of

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the Fen wheels, and it was stated (page 274) that if scoop wheels were thoroughly well designed and made they should have an efficiency of 75 per cent., exclusive of the engine. Wheels and screws were very much heavier than centrifugal pumps of equal pumping capacity, and they ran at very slow speeds and required the discharge level to be constant; so that, taking all points into consideration, he believed that for lifts below 30 or 35 feet centrifugal pumps were the best to adopt for general purposes. He preferred to use a larger diameter of disc than was usual, so as to run at a moderate speed and thereby avoid excessive wear and tear; and this saving more than compensated for the loss of efficiency due to the extra disc friction.

For pumping out graving docks, where the height of lift was a varying one, centrifugal pumps were undoubtedly the best to use. In Fig. 45, Plate 16, were shown the results of experiments with two of the large centrifugal pumps made by his firm for the Tilbury docks; from which it would be seen how the discharge decreased as the lift increased, the speed of the discs not varying much during the trials, except at the very end when it was increased in order to run the steam down in the boilers. The blades of the fans were made flatter curves than they would have been, had the lift been a constant one.

Mr. Henry Davey asked whether the reason could be given for the lower efficiencies of the reciprocating pump that were shown in Fig. 44 for lower lifts.

Mr. Mair replied that the efficiencies he had given in Fig. 44, Plate 16, were simply the results of actual experiments.

Mr. H. D. Pearsall, referring to the subject of hydraulic rams, which was dealt with in the concluding portion of the paper, considered the use of hydraulic rams on a larger scale than hitherto was no doubt a very desirable object if it could be attained. The author's experiments with rams were undoubtedly a valuable contribution to the subject; but they had not, as he had candidly

admitted, solved all the problems presented. The reason of the difficulties encountered, and the means for their removal, he would endeavour to show. Until the air cushion or dash-pot was added, it was stated on page 58 that the shock of the closing valve was too great for the safety of large rams; and this had indeed always been found by other experimenters. And when the air cushion was added, it would further appear (page 58) that the ram had not power enough to raise any water to more than five times the height of the propelling head. Moreover the cushioning action was not carried very far, and seemed still quite imperfect; for on page 59 it was stated that the action was smooth and regular "when the closing motion is not too abrupt." Those facts were valuable and interesting; but the author had not pointed out, and did not seem to be aware, that the loss of power observed was the natural consequence of adding the air cushion, which evidently acted by checking the motion of the waste valve and causing it to move slowly towards the end of its stroke. That was the moment when the water which was seeking to escape through the valve was flowing at its greatest velocity, while the smallness of the orifice was tending to check the flow of the water. If the motion of the valve was made slow, that action lasted for a longer time, and the flow of the water was checked very considerably. Such a check was so much absolute waste of energy, and fully accounted for the want of power in the ram. How much energy was thus lost was not difficult to estimate. If the resistance had the effect of reducing the velocity of the water by only one quarter, the energy of the column of water was reduced one half: that is to say, one half of the whole available energy of the machine was consumed in overcoming this useless resistance. As a matter of experience, great loss of effect had invariably resulted from all attempts to soften the blow of the waste valve, whether by dash-pots or balance weights, or by any other of the devices which had been tried from time to time; and the above explanation showed why. About three years ago, when in want of some very large rams, he had studied their construction and had come to the above conclusion, which at first sight seemed to indicate that it was impossible to make large rams at all; for it was evidently impossible to bring large valves

(Mr. H. D. Pearsall.)
to their seats with the very great quickness which was absolutely necessary in order to avoid great loss of efficiency. Ultimately however he had succeeded in evading the difficulty by adding an ante-chamber, into which some of the water could flow while the waste valve was closing: so that the act of closing did not check the flow of water, and therefore the motion of the valve in closing might be made slow without detriment. In Figs. 42 and 43, Plates 14 and 15, which were vertical sections of a machine lately made on his design, the ante-chamber added for this purpose was shown at A. When the waste valve W was opened, the water-level fell in the ante-chamber, and thus admitted air through the passage G: so that, while the waste valve W was again closing, the water could rise in the ante-chamber without meeting with any resistance from the air, which escaped freely through the passage G. The consequence was that the closing of the waste valve W did not tend in the slightest degree to check the flow of the water; and hence there was no need to close the valve with great rapidity. This device therefore removed the chief difficulty in making large hydraulic rams. The waste valve was an annular balanced sliding valve, actuated by a motor M which was driven by the small quantity of air that was forced into the air-vessel V together with the water at each stroke. The motor both opened and closed the waste valve, at the exact times found most suitable. In order still further to avoid any shock of the waste valve W on its seat in closing, the new form of valve shown in Figs. 42 and 43 had been devised, the principle of which was that the valve was not brought hard home to its seat at all, but was only brought close up to its seat without actually touching it. The seat consisted of a loose hanging flap F of india-rubber; and when the pressure rose inside the flow pipe P, it pressed the flap against the edge of the valve, and so completed the closing.

The true theory of hydraulic rams appeared to be so little understood that he should like to make one observation on it, especially as the author appeared to sanction an erroneous theory by speaking in page 58 of the "percussive impulse of the current." There need not necessarily be any percussive action at all in the ram. If a mass of 2 tons was in motion with a velocity of 4 feet per second,

it possessed a stored up energy of 1 foot-ton, and would overcome a resistance of 1 foot-ton whether that resistance acted gradually through a long time or suddenly through a very short time. This he considered was the true theory of the ram; while the theory which represented it as necessary that a blow should be struck by the momentum of the water was not correct. The action of the machine he had made was entirely successful; it was as smooth as the best reciprocating pump, and gave the very high efficiency of about 70 per cent. In this way he believed that the problem of applying the hydraulic ram to large quantities of water had now been solved; for in the first machine made, 4 tons of water moving at a high velocity were brought to rest at each stroke with perfect ease and gentleness, and without sacrificing any efficiency in obtaining that gentle action. The flow through the flow pipe was $1\frac{1}{2}$ million gallons of water per day. Moreover the form of the machine was such that it was equally adapted for very much larger sizes. From thus performing in one simple machine and at one operation what had hitherto required the combination of two or more complex machines, it seemed obvious that a great economy both of construction and of power must result. One of these hydraulic rams was now being erected at St. Mary Cray, near London, where it could be seen at work.

Mr. George Richards had hoped to hear some remarks upon the principle of balancing the vertical shaft in such cases as those described in his father's paper. Though not himself acquainted with the subject of hydraulics, he fully appreciated the difficulty of running heavy upright shafts and lubricating them, which appeared to him to be one of the principal points in the paper: whether novel or not he did not know. In discussing a better form of thrust bearing, it seemed to him to have been overlooked by Mr. Davey that the great point was to avoid thrust bearings of every kind; and if they were avoided, it appeared to him that a very great difficulty had been overcome. For his father's information he should be glad to hear whether the principle described in the paper was entirely new, or whether any of the members had seen in use that method of

(Mr. George Richards.)
overcoming the heavy weight and friction, and the consequent trouble in working pumps of that class, especially when they were obstructed by sand and dirt.

Mr. Henry Davey explained that the onion bearing which he had described was not meant to carry the weight of the pump and shaft altogether, but only part of the weight. The pump to which he had applied that bearing was constructed on the principle described in the paper, but with a separate shield S immediately over it, Fig. 41, Plate 14, which was carried by three suspending bolts B from the girders overhead; and the clearance round the pump rim formed a small opening from the space beneath the shield into the delivery of the pump, so that by making the shield of large enough diameter the pump could be altogether supported, and its whole weight taken off the bearings. It was not usual however to take the weight entirely off, but to leave a little weight on the spindle; and it was this small remainder that was carried by the onion bearing.

Mr. William Schönheyder mentioned, in reference to Mr. George Richards' enquiry, that the balancing of vertical centrifugal pumps had been effected many years ago by the late Mr. David Thomson, who had constructed a large number of such pumps, and had done a great deal to improve centrifugal pumps. His centrifugal pump at Leith, made in 1862, which had been referred to by Mr. Mair, was constructed in the way already described by Mr. Davey; and the joint between the lips of the fixed shield above and the revolving pump had to be carefully attended to, otherwise there would be a certain leakage of water into the space under the shield, whereby the balance would be destroyed. Not only had Mr. Thomson balanced a portion of the weight of the shaft, but in one or two instances he had overbalanced it: so that, instead of a downward pressure on the collar bearing provided at the top of the pump, there was actually an upward pressure. The arrangement adopted by the author in the balanced pump shown in Plate 6, with vanes on the back of the pump wheel for circulating the water in the balance

chamber, appeared to him to be a very good step in the right direction. Probably in order to get the axial thrust properly balanced in this way, some experimenting would be required; but the arrangement seemed a capital one for ensuring a very perfect balancing of the pump.

The increased friction of the pump if made of a large diameter had been spoken of in the paper and by Professor Unwin. Increased friction was also occasioned if the pump was driven at too high a speed; and it was to a large extent owing to the way in which as a rule the vanes were made that pumps were obliged to be driven at high speed. The present shape of the vanes was due he thought to some experiments made by the late Mr. Appold on what were then the best centrifugal pumps; but those experiments he believed had included only three shapes: the curved form shown in Fig. 26, Plate 9, the radial form with perfectly straight vanes, and straight vanes inclined backwards. None of these three however was the best form. A study of the turbine, in connection with Professor Unwin's remark that a centrifugal pump was simply a reversed turbine, would lead to a better shape for the vanes, something like that adopted by Mr. Thornycroft in some of his turbine propellers for propelling boats by a stream of water issuing from the stern; and also like that adopted in the centrifugal pump recently erected in Egypt, of which Mr. Mair had spoken. That was the only way in which higher efficiency could be obtained, and the speed of the pump kept down to a minimum of less than the velocity due to the head against which the pump was working. When pumps were constructed in that manner he believed efficiencies as high as 70 per cent. were to be obtained.

He had had an opportunity of seeing at work at Wolverhampton the hydraulic ram described by Mr. Pearsall. It had a 12-inch driving pipe, and he believed it was the biggest hydraulic ram ever worked successfully and quietly; it worked as quietly as any good pumping engine.

The President was sure that every one who had read the paper would feel much indebted to the author for having taken the trouble

(The President.)
out in California to send the information which he had furnished to the Institution. They would therefore ask his son, Mr. George Richards, to convey to him their warmest thanks for the paper, and their best wishes to him for success with his machinery in California.

Mr. E. B. Ellington wrote that he could confirm Mr. Mair's remarks as to the reduced efficiency of reciprocating pumps working against low heads of water, from his own experience of what might be called reversed pumps, namely hydraulic lifts. The efficiency of these machines fell very rapidly as the pressure of water decreased below 70 feet head; and he had never succeeded in producing an efficient hydraulic lift with less than 65 feet head. The friction of water in hydraulic machines was probably constant for all pressures, and the friction of rams passing through glands was also almost independent of pressure; this was no doubt the explanation of the phenomena referred to.

Mr. Richards wrote, in respect to Mr. Davey's remarks (page 65) upon the collar bearing, that it seemed to have been overlooked that these bearings had no duty to perform except at starting and until the pump wheels attained their full velocity, and that under these circumstances the form of bearing was not of much consequence. Had the thrust been continuous, a Schiele bearing would have been employed. The onion bearing described by Mr. Davey undoubtedly owed the excellence of its performance to its approximation to the "curve of equal tangents," in which the angle of the faces corresponded with the velocity of the surfaces. From the baffling vanes used in the compound or double-wheel pumps, there was obviously and unavoidably a loss of energy. The water had to be compelled to return from the circumference to the centre, and within a small space. To enable it to do this, its energy must be destroyed; and the baffling vanes tended to relieve the wheel vanes from drag or friction, and only destroyed energy that would at any

rate be lost. It must also be considered that the energy of the water, so important a factor at low heads, was to a great extent lost at high heads, because of the difference between the velocity of the wheels and that of the water in the discharge casing, even when a volute form was employed; and in the case referred to the energy of the water was so inconsiderable that baffling in any way caused but little loss in the pump's duty when the head exceeded 60 feet.

In the case of the hydraulic rams with an air cushion to stop the escape valves, Fig. 33, Plate 11, it was to be observed that the escape valves were closed before the air cushion began to act, and that the air acted as a yielding resistance to the energy of the driving column, the same as if the air was contained in a separate or auxiliary chamber. If this resistance began before the escape valve was closed, there would evidently result the loss of energy pointed out by Mr. Pearsall (page 69). There was no trouble and apparently a high efficiency in working rams in this manner with an air cushion under low pressure; when the discharge resistance was increased to 80 lbs. per square inch or upwards, a new set of conditions seemed to be called forth. The balanced oscillating or radial valves, Plate 12, worked almost without friction, closed themselves when released, and were in some respects at least preferable to sliding valves, especially when there was sand in the water.

ON THE POSITION AND PROSPECTS OF ELECTRICITY AS APPLIED TO ENGINEERING.

BY MR. WILLIAM GEIPEL, OF EDINBURGH.

In the present paper the author purposes confining his remarks to those branches of Electric Engineering which involve the employment of considerable power and are in some way connected with the use of dynamo machines. The principal of these may be treated under the four following heads:—

I. Electric Transmission and Distribution of Power.

II. Electric Locomotion.

III. Electric Lighting.

IV. Electric Metallurgy.

I. ELECTRIC TRANSMISSION AND DISTRIBUTION OF POWER.

In the near future this branch of electric engineering will probably occupy more attention and call forth more outlay of capital than either of the three others mentioned above; already indeed it is commanding a great deal of attention. Owing to its simplicity, the ease with which an electric motor can be applied to any purpose requiring power, and its high efficiency, it is certainly an approach to an ideally perfect system of transmission. No greater contrast can be imagined than the difference between the position of electricity in this country and in America. On the other side of the Atlantic, although the science of electricity is much behind, the practice is far ahead of our own. European science has supplied an agent, the value of which has been recognised by American engineers; and now in the United States the applications of electric motors are already rivalling and will soon excel in importance the application of electricity for lighting purposes. It is to be remembered however that there, owing to the high price of coal, the use of steam-power

is a more serious consideration than here; they have also in many places abundance of water-power which can be utilised by electric transmission. Notwithstanding these differences, there is in our own country an almost unlimited field for the employment of this mode of transmitting power cheaply to a distance, and of distributing power generated at a central station to a number of users in the neighbourhood.

Were it not for the cost of the dynamos and motors, electricity would supersede to a great extent the use of belts and shafting. In large works, where high speeds are required and the demand for power is variable, the efficiency of belts and shafting is very low indeed. As much as 25 per cent. of the power may be absorbed by the shafting when the full number of machines are in use; and in such a case with half the machines in use the loss of power rises to nearly 50 per cent., while in the extreme of driving only a single machine even 99 per cent. may be lost. With electricity, on the other hand, no power is being used in keeping the transmitting medium in motion, the conductor being stationary; the loss takes place only whilst power is actually being used by the motors, each of which drives its own machine. In fact the percentage of power lost in the transmitting medium becomes smaller as the amount of power transmitted is reduced, which is exactly the converse of what happens with belting and shafting. For the sake of illustration and comparison, let it be assumed that a loss of 25 per cent. of power would take place in the electric conductor when the full load is on: although in reality the loss would never be above 10 per cent., and need not be more than 5 per cent. Then with half load the loss would be $12\frac{1}{2}$ per cent., and so on; and with one machine possibly one-tenth of 1 per cent. might represent the loss in the conductor. When it is remembered in how many cases the average load in a factory is less than half the maximum, it is evident that this point is one demanding the greatest consideration. In New York, where a large number of motors are supplied with current from the electric-light mains, it has been found by experience that on an average less than one-third of the whole number of motors are in use at any one time.

The depreciation of the electric conductors is comparatively small; but whether the saving of renewing belts and of lubricating shafting would not be counterbalanced by the wear and tear of motors, is a question to be settled by individual experience. The advantage however of getting rid of shafting, thereby obviating the necessity for additional stability in the building and doing away with constant lubrication, and the further advantages of saving the space and light absorbed by belts, and of the ease with which the conductor can be shifted to suit any desired alterations in position of machines, are also very important matters.

The distribution of power by electricity from a central station to small users will, in the author's opinion, form in many towns a larger business than the lighting. Both can be done from the same mains and generators, just as is the case with gas; it is merely a question of economy and convenience as to whether gas or electricity should be used. The encouragement of small industries has long demanded some cheap means of obtaining power in small quantities, say from $\frac{1}{2}$ to 25 HP. The gas engine has not altogether met the requirements of small establishments, although needing but little attendance; for the first cost of even a small engine is high, and the amount of gas consumed is large. Moreover the speed is generally irregular, owing to the intermittent impulse, which is more especially noticeable with light loads; and a considerable amount of wear and tear takes place in the valves and working parts.

An electric motor can be started and stopped at will with the greatest ease; it requires the smallest amount of attention, occupies the minimum of space, and can be placed in almost any position. An ordinary shunt-wound motor will run at an almost constant speed, with a maximum variation of only 5 per cent. from running light to fully loaded; this fact was first pointed out in an interesting paper in the Philosophical Magazine for January 1886 by Mr. Mordey, who has done much valuable work in the perfecting of the modern dynamo machine; he has kindly furnished the diagram, Fig. 1, Plate 17, showing the result of some tests of a Victoria motor for change of speed under variable load, which illustrates the remarkable constancy of speed attained. This exceedingly close

regulation was obtained by using a simple shunt motor of suitable construction, and without any accessories such as the many forms of governing devices to which so much attention had previously been devoted. The result shows that such a motor possesses a practically perfect power of self-control, not only over its rate of speed with varying load, but, what is of equal importance, over the energy absorbed by it; for it helps itself, as it were, to only such an amount of energy as will enable it to deal with the work imposed on it. Another advantage in the use of shunt motors is that they act as generators when themselves driven by any extraneous power, without any complication of switch gear such as is required with a series motor. This fact was first pointed out by Sir William Siemens in a paper read before the Society of Telegraph Engineers on 3 June 1880. In such a system, where railways, lifts &c., are being worked by motors, the current generated by descending trains or loads might suffice at times to supply the rest of the motors with sufficient current for their work, without absorbing any current from the dynamo; at any rate it would reduce the amount of current required to be supplied by the dynamo. The first cost is also small compared with that of a gas engine. A 1 HP. motor will cost £20 against £100 for a gas engine. The cost of running a gas engine is about one penny per horse power per hour for gas alone; the same power generated by a dynamo driven by an efficient steam engine costs only about one farthing, current being supplied from street mains just as gas is.

As small steam engines are being superseded by gas engines wherever the outlay for the latter can be afforded, the competition in regard to small powers lies between gas and electricity, and steam may be left out of the question. There is of course a limit above which steam becomes the cheapest; and probably 10 HP. may be taken as about that limit in this country. In Boston in the United States, where some hundreds of motors are supplied with electricity from central stations, they range from $\frac{1}{2}$ to 15 HP., and are working lifts, printing establishments, small machine-shops, and watch-making, tailoring, boot-making, and similar industries. Their working seems to be highly appreciated; and the author understands

the users would be willing to pay even 25 per cent. more for them, in consequence of their convenience and regularity in working. In Geneva within a radius of a mile and a quarter there are no fewer than 175 motors at work, varying from $\frac{1}{2}$ to 70 HP., supplying power to small workshops and for other purposes, the electric power being obtained from dynamos and turbines which are driven by water power derived from the Rhone. The installation is paying its way, and is about to be largely increased. At the Falls of Niagara plant is being put down to distribute power obtained from the falls to neighbouring towns, including Buffalo which is 20 miles distant; the amount of power is stated at 15,000 HP., of which 10,000 HP. is contracted for at £3 per horse-power per annum for power and lighting purposes in Buffalo.

As an interesting example may be mentioned a 6 HP. motor recently erected by the Brush Company of Cleveland, Ohio, in a printing establishment, where it was connected with the regular arc-light circuit. It takes the place of a 10 HP. steam engine, which had sometimes come to a standstill under its load. It drives about 70 to 80 feet of shafting, three cylinder presses, four platen presses, one large paper-cutter, and one very heavy lift; and by a 4-inch belt carried up through three floors it also drives three ruling machines and four paper cutters. It does its work splendidly, and its motion is steady and regular. It has proved to the proprietor's satisfaction that printing offices could well afford to employ electricity instead of steam, even in cases where the first cost might be more. In many other towns in America, where the electric-light mains are within reach, the number of motors already in use is very great; within two years 5,000 motors have been supplied by one firm alone, and the author understands that the Brush Co. are turning out as many motors as dynamos.

In some places in this country, and more especially in Lancashire, it is customary for power to be supplied from a large steam engine to neighbouring buildings, which are let out as separate workshops. In such instances however the power supplied is more frequently above than below 10 HP., and probably it would not pay to introduce an electric motor. Still it should not be forgotten that in renting

these workshops considerable inconvenience may be incurred as regards the locality of the premises for the manufacture; moreover the rent is often disproportionately high.

Many schemes have been propounded for distributing power in manufacturing districts by means of steam, compressed air, and water pressure, each of which is in use to a somewhat limited extent; and as all of them have been known long enough, it may seemingly be inferred from their limited employment that there is not much to recommend their extended use commercially. With steam, the condensation in the pipes causes loss of pressure, and results in wet steam being supplied to the engines. Compressed air cannot efficiently be worked expansively, and is attended with loss of heat in the compressor. Water pressure commonly involves using the maximum power, whatever the work required. Besides these prominent faults of the three several methods, what is of the greatest importance and common to all three is that the generating plant has to be used almost exclusively for supplying the power, and cannot be utilised for other purposes in addition; whereas with a central electric station the engines and dynamos serve to generate current for lighting purposes also at night.

Collieries.—In collieries electricity will be largely adopted in the near future. For underground hauling, pumping, ventilating, and drilling, it can readily be applied with an efficiency double that of compressed air. With a well-arranged installation 75 per cent. of the brake power of the engine will be utilised on the shaft of the motor.

For hauling and pumping, wire ropes or rods are the greatest competitors of electricity, which obviates the following disadvantages in connection with them:—chance of break down through strain; wear and tear; mishap to guides through falls of roof or dirt; trouble and expense of oiling the guides; and room required at pit mouth or at bottom for engine, pulleys or levers, or other gear. An illustration of electric pumping in mines is given in Fig. 4, Plate 18. As the tendency in mines in this country is towards a reduction of working hours, the question of mechanical haulage

becomes most important, because horses must be fed whether at work or idle, and the cost of haulage by horses therefore increases as the working hours become reduced.

For ventilating and drilling, compressed air is perhaps most largely used; and one of the great points in its favour is that the exhaust is available for supplying fresh air to the miners, and for driving out the foul gas after the firing of shots. But the cost of the compressed-air machinery is heavy, as is also that of the pipes for conducting the compressed air from the compressor to the place where it is used. The cost of electric plant is somewhat less, and the efficiency is very much greater; while by using old haulage ropes as conductors the cost of this item is rendered very small.

At Trafalgar collieries, in the Forest of Dean, there is an interesting instance of pumping on a small scale. A Gramme machine driven at bank supplies current to a motor in the mine 800 yards distant from it. A current of 15 ampères at 100 volts, equal to 1,500 watts or 2 horse-power, is found sufficient to work the pump, which is double-acting, 5 inches diameter and 8 inches stroke, and runs up to 70 revolutions or 35 gallons per minute, lifting about 90 feet. The entire installation cost £250; it has been working about four years, and has given so much satisfaction that additional plant has lately been put in at a distance of 1650 yards from the pit shaft for lifting 120 gallons per minute 300 feet high, the distance between the pump and generator being 2,200 yards. A double-throw pump with 9-inch plunger and 10 inches stroke is driven at 25 revolutions per minute by spur gearing reducing 6 to 1, the small pinion being driven by a belt from the motor. Current is conveyed to the motor by a conductor composed of nineteen wires No. 16 S.W.G. (0·065 inch) thick, giving 0·065 square inch total sectional area, insulated and carried on earthenware insulators; an old 4-inch wire-rope serves for the return circuit. The efficiency obtained throughout is only 35 per cent.; but as much as 6·49 HP. or 22 per cent. is lost in the engine alone, which is an old one. The cost of engine and electric plant and pump complete was £774, without pipes. The

weekly cost of maintenance is given as follows by Mr. Brain, the colliery manager :—

	£	s.	d.
Engineers, half time	1	8	0
Men underground, full time	2	9	0
Small coal consumed, say 36 tons at 1s.	1	16	0
Oil, waste, and sundries		7	0
Interest and depreciation, say 15 per cent.	1	17	0
Total per week	£7	17	0

Total per annum £408, showing a yearly saving of £470 on the water-power that was superseded. The cost of the water raised is 0·02 penny per HP. per hour, and 1·8 pence per 1000 gallons. At the same collieries a 6-ft. fan is also being worked by an electromotor at 1,800 yards distance from the generator.

Another interesting example of pumping is afforded by the recent introduction of electricity for this purpose into St. John's colliery, Normanton, where 39 gallons per minute are raised 530 feet, equivalent to 6·3 HP. of work done. An old girder-beam engine is utilised to drive the dynamo, and indicates 14·2 HP. with full load. The efficiency throughout is therefore 44·4 per cent. The power lost in the different stages is as follows :—

	HP.	per cent.
Engine and dynamo running light	1·7 HP. =	12·0 per cent.
Conductors	0·88	6·2
Motor and first shaft	2·8	19·7
Driving pump empty	2·0	14·1
Other losses	0·52	3·6
Total Loss	7·9	55·6
Useful Work	6·3	44·4
	14·2 HP. =	100·0 per cent.

It will be seen that only a small part of the loss takes place in the electrical plant, the greater part occurring in the pump, engine, and gear. The pump is driven by toothed wheels, which are worked from the motor by a cotton belt, in order to obviate transmitting the vibrations of the pump back to the motor. This plant is being extended to pump in addition 120 gallons per minute against a head of 900 feet.

At Thallern colliery, on the Danube, where electricity has replaced steam for pumping, it has been found after several months' work that a considerable saving in coal is effected; also that the temperature of the pit is reduced some 14° Fahr., steam having previously rendered the atmosphere of the mine unbearable.

In the mines of Blanzy, in France, a ventilating fan is driven from a generator at bank. The fan is 150 yards in, $2\frac{1}{2}$ feet diameter by $11\frac{3}{4}$ inches broad, and runs at 730 revolutions per minute. The temperature at the face has been reduced 15 degrees, from 95° down to 80° Fahr., since its introduction.

Shipyards.—In shipyards and similar works electricity has already proved itself a suitable and economical means of transmitting power for riveting, drilling, &c. The electro-magnetic tools described in Mr. Rowan's paper at last year's Summer Meeting (Proceedings 1887, page 323) are being successfully employed in yards at Dumbarton. This system possesses the additional advantage that the tool can be firmly held to its work by magnetic attraction alone, without the use of bolts, so that no holes need be left for hand-riveting as is required with other machine-riveters.

Transmission to great distances.—The transmission of power to great distances is not of such vast importance here as in the colonies, although even in the small sluggish rivers of this country there are large amounts of power running to waste. In many places where works have been erected for utilising water-power, it has been at the sacrifice of convenience of situation, or of a ready and cheap means of receiving and despatching goods; whereas by means of electricity the same water-power might have been transmitted to a locality more suitable for the works. For short distances it does not pay to transmit water-power by electricity, owing, as previously mentioned, to the cost of dynamos; in such cases transmission by shafting or wire ropes is cheaper. But for long distances shafting is out of the question, wire ropes become more expensive, and electricity is cheapest. In Table 1 is shown the first cost of plant per horse-power transmitted through

TABLE 1.—*First Cost of Plant per Horse-power transmitted.*

Total Power Transmitted.	System of Transmission.	Distance of Transmission in yards. 110	1,100	11,000	22,000
H.P.		£	£	£	£
5	Electric	75	81	142	210
	Hydraulic	41	97	610	1280
	Pneumatic	73	210	1090	2060
	Wire-Rope	6·5	61	760	1220
100	Electric	32	35	59	87
	Hydraulic	14	28	164	310
	Pneumatic	26	34	109	192
	Wire-Rope	1·1	8·4	81	162

different distances by electricity, water, air, and wire rope. There is of course a limit beyond which it would not pay to transmit power, because with the distance the capital outlay increases, until the interest thereon outweighs the cost of the coal which would be consumed by a steam engine on the spot. Wire rope is perhaps cheaper for distances of less than one mile, although the disadvantages of having to lubricate pulleys and to provide substantial supports would in many cases compensate for the higher cost of electricity. The limit of distance to which it is economical to transmit water-power increases with the amount of power transmitted. From Table 2 (page 86), showing the cost of one horse-power per hour,* it appears that, when the power is generated by a fall of water, 5 HP. can be transmitted 11,000 yards at the rate of 0·52 penny per HP. per hour by electricity, while at the same rate also 100 HP. can be transmitted 22,000 yards, that is double the distance. The transmission of steam power over long distances is seen from the same table to be not economical; small powers, say up to 10 HP.,

* This is a modification of a table given in Mr. Kapp's work on "Electric Transmission of Energy." The original table is based on the investigations of Herr Beringer and on the cost of power as determined by Professor Grove.

TABLE 2.

Cost per Horse-power transmitted per Hour.

Total Power Transmitted.	System of Transmission.	Power generated by a Steam Engine. Distance of Transmission in Yards. 110	1,100	11,000	22,000	Power generated by a Fall of Water. Distance of Transmission in Yards. 110	1,100	11,000	22,000
H.P.		Pence.	Pence.	Pence.	Pence.	Pence.	Pence.	Pence.	Pence.
5	Electric	2·25	2·41	3·29	5·20	0·35	0·37	0·52	0·84
	Hydraulic	2·50	3·15	10·50	19·00	0·29	0·48	2·48	4·79
	Pneumatic	2·70	3·30	9·53	16·72	0·40	0·58	2·40	4·45
	Wire-Rope	1·13	1·88	10·40	22·70	0·11	0·30	2·50	4·86
100	Electric	1·79	1·91	2·63	4·08	0·20	0·23	0·32	0·50
	Hydraulic	1·62	1·78	4·15	6·84	0·16	0·19	0·72	1·14
	Pneumatic	2·00	2·09	3·10	4·50	0·22	0·24	0·48	0·83
	Wire-Rope	1·07	1·22	8·83	9·73	0·08	0·11	0·48	1·19

may be transmitted as far as three miles; but larger powers not so far, because for larger power a local engine becomes more economical.

As an interesting instance of the transmission of power by electricity over long distances, that at the Phœnix Gold Mines in New Zealand may be referred to. The current is generated by two No. 8 Brush machines, each capable of giving 20,000 watts or 26 HP.; they are driven by Pelton water-wheels, with a head of 180 feet. The current is conveyed to the motor about three miles distant, and back again, by a No. 8 B.W.G. copper wire (0·165 inch thick) nearly six miles long, supported on telegraph poles. The power lost in the line is only 3 HP. A Victoria motor is used, running at about 350 revolutions per minute; and the power is transmitted to the machinery by a belt.

Deprez succeeded in demonstrating practically that 52 horse-power could be transmitted over a distance of 35 miles, namely from Creil to Paris, through a copper cable equal in section to a wire of less than 0·2 inch diameter. But his machines were not efficient, the power required to drive the dynamo being 116 HP., of which 44 per cent. was lost in the dynamo and motor, and 11 per cent. in the 70 miles of the outward and return wire. There is no reason however why much more efficient results should not have been obtained; as much as 18 per cent. of the total power was absorbed for maintaining the magnetism of the field of the dynamo, whereas in a well-designed machine less than 5 per cent. should suffice.

Mr. C. E. H. Brown, of Oerlikon, has succeeded in transmitting by electricity 50 horse-power from water power at Kriegstetten over a distance of 5 miles to Solothurn in Switzerland, with a commercial return of over 70 per cent. Two series-dynamos and two series-motors are arranged on the three-wire system. Each of the three wires is $\frac{1}{4}$ inch diameter, consisting of bare copper suspended on poles about 40 yards apart, with fluid insulators for ensuring good insulation. For a span of 130 yards across the River Aare, silicium-bronze wire is used, which has the same conductivity as copper and a tensile strength of 30 tons per square inch. The current used is

15 ampères, and the potential difference at the terminals of each dynamo is 1,250 volts. The resistance of the line is 10 ohms, and the loss in it is a little over 3 HP., or 6 per cent. of the total power. The loss in dynamos and motors is 24 per cent., being much less than in Deprez's machines where it was 44 per cent.

At Hatfield, on the Marquis of Salisbury's estate, the River Lea is utilised to generate electricity, which is transmitted to the house and over the estate for a variety of purposes. The distances and distribution of the machines are shown in the plan, Fig. 5, Plate 19. Two water-wheels and a turbine are used, which drive a 40-HP. Siemens alternating-current dynamo for lighting the house, and also a 16-HP. Brush machine, for arc-lighting at night, and in the day for working the motors at the house and on the farm. Those at the house drive pumping and ice-making machinery, and a 24-inch Blackman air-propeller fixed in the roof for ventilating; on the farm the motors are used for elevating hay and corn sheaves to the tops of the stacks, for thrashing, for cutting rough grass with a chaff-cutting machine for ensilage, in fields extending to a distance of two miles, for grinding corn &c. to make fodder, and for other purposes. The motors have also been used for pile driving, for making cofferdams where necessary in the river; and also for dredging the river and clearing it of weeds. A Gramme motor, capable of raising 2,500 to 3,000 gallons per hour, pumps the town sewage into a tank at a height of 30 feet for irrigation. The conductors are carried overhead on poles about the farm, and underground in wooden troughs to the house.

In favourable districts the supply of power to farmers by means of electricity is a subject well worthy the consideration of capitalists. If water power is not to be obtained as the prime mover, then steam power must be used as is now the custom, but in a more economical form than in a portable or traction engine. The expense of taking these engines about the farm, both in coal and wages, must render them costly to the farmer in respect of the power actually used. An economical engine could be fixed, for generating an electric current to be transmitted through overhead conductors carried on poles along the roadside.

II. Electric Locomotion.

The practical methods of accomplishing electric locomotion seem to the author to be the four following:—

Firstly, the use of a third insulated rail or conductor to convey the current from the generator to the motor carried on the locomotive, contact being made by a wheel or a sliding spring or brush; while the two ordinary rails serve as a return circuit, the current being conducted from the motor to the rails through the frame, axle, and wheels of the locomotive.

Secondly, the employment of an overhead conductor supported on poles or from the roof of an arch or tunnel, contact being made either by a carrier on wheels running along the conductor, or by rubbing. The return circuit may be either through a second overhead conductor, or through the ordinary rails as in the third-rail plan.

Thirdly, the use of an underground insulated conductor, placed in a conduit between the rails, and conducting the current from the generator through a contact carriage to the motor, whence it is conveyed back through the frame, axle, wheels, and rails.

Fourthly, the employment of storage batteries, placed preferably under the seats of the car, Fig. 6, Plate 19, with the motor and gear underneath, or the whole placed on a separate locomotive.

The plan of using the ordinary rails as positive and negative conductors, and insulating the wheels or axles of the cars, is attended with the objection that, owing to the rail supports having to carry heavy loads, there is difficulty in insulating the rails sufficiently to prevent excessive leakage to earth.

Of these four methods the first two are the cheapest and most efficient, but are applicable only to railroads; while the two other plans, of an underground insulated conductor, and of storage cells on the car, are both applicable to street tramways.

Gearing.—Owing to the high speed at which electric motors require to run and the limited space available for them to occupy, the mode of gearing the motor to the axle of the locomotive or car forms an important consideration, more especially in places where

the motor is placed upon the car which carries passengers, when noise and vibration would be most objectionable. The following five methods of gearing are those more generally employed:—(1) worm-wheel gearing; (2) pitch-chain gearing; (3) leather belting; (4) rope, either endless or not; (5) toothed wheels.

Worm gearing appears from Mr. Holroyd Smith's experience at Blackpool, where his electric tramway is worked with an underground conductor, to be the best for tramcars. Although as a rule it is not efficient, yet if well designed and properly lubricated it can be rendered more efficient, and probably is fairly suitable for this purpose. Some tests made by Mr. Reckenzaun show a maximum efficiency of 87 per cent. The author thinks that a combination of toothed wheels and friction gear, such as has been introduced by Mr. Raworth for driving dynamos in electric lighting with excellent results where space is a desideratum, would make a silent working and durable form of gear: the friction gear would serve to reduce the speed from the motor to a countershaft; and from the latter the driving wheels of the car would be driven by toothed wheels. The form of gear employed of course depends greatly upon the nature of the traffic and of the rolling stock.

Third Insulated Rail.—As an example of an electric railway with a third insulated rail, that at Portrush, Ireland, is probably the most interesting, as being one of the first started in the world and also one of the longest; its total length is 6 miles. The plan and profile shown in Figs. 8 and 9, Plate 20, have been kindly furnished by Messrs. Siemens, by whom the railway was planned. Power is generated by two 50-HP. turbines, driving a dynamo which is capable of generating 100 ampères at 250 volts; the current is transmitted from the River Bush through a distance of 1,600 yards to the railway, the resistance of the line being 1·9 ohm. Pitch-chain gearing is used, and gives satisfaction. The working expenses amount to less than threepence per car-mile.

Another instance, also in Ireland, is the Bessbrook and Newry tramway, which is 3 miles long and 3 feet gauge, and is actuated by water power. Photographs showing the arrangement of the cars have been kindly lent by Dr. Edward Hopkinson,

to whose designs the railway was constructed. A turbine which develops 62 HP. drives two Edison-Hopkinson dynamos, each capable of giving out 25 HP. at 250 volts. The third rail is of channel-section steel, supported in wooden blocks which apparently act admirably as insulators, the leakage being only $\frac{1}{4}$ ampère per mile or 0·3 HP. in all. A train consists generally of one passenger car constructed to carry thirty-eight persons, and three goods wagons, each carrying 2 tons freight. The maximum speed that can be attained is 15 miles per hour. Here also chain gearing is employed. The cost per train-mile is 3·3*d.* during the busy months, and 4·2*d.* in slack months; these figures however do not include anything for depreciation on the cost of construction of the railway which was £2,500, nor for general supervision.

Overhead Conductors.—The electric railway at Moedling, near Vienna, is a good example of the employment of overhead conductors. The number of passengers carried during the year 1886 was 342,257, according to Mr. Reckenzaun, and the average cost 3·42 pence per car-mile; the coal consumption per car-mile was 13·4 lbs. of very inferior brown coal. The current is generated by six Siemens dynamos, driven by three portable engines of 12 nominal horse-power each; the use of these engines may account for the somewhat high consumption of coal. The overhead conductors, which are carried on posts 18 ft. high and 90 ft. apart, consist of slotted tubes in lengths of 15 ft. each, soldered together; a contact carriage slides within the tube, which is 1 inch diameter inside. Spur gearing is used, but apparently is not satisfactory; the objections to it are the rapid wearing out of the high-speed pinions, the great weight of the gear, and the noise and vibration caused.

The Frankfort Offenbach electric railway, which was opened for traffic on 10 April 1884, is similar to that at Moedling, the current being brought to the moving cars by means of slotted iron-tube conductors carried overhead. The length of the line is about $4\frac{1}{2}$ miles; the gauge is 1 metre (3 ft. $3\frac{3}{8}$ ins.). The sharpest curve has a radius of $98\frac{1}{2}$ feet; the steepest incline is 1 in 30, and only 18 per cent. of the line is level. The average speed of the cars is $7\frac{1}{2}$ miles per hour.

Two cars coupled together start from each end of the line every twenty minutes. Each car has seats for eighteen passengers and standing room for twelve more, the gross weight being 4 tons. The motor is placed under the floor of the car, and the connection to the wheels is made by toothed gearing. The generating station is at Ober-rad about the middle of the line, and contains one twin engine of 240 I.H.P. and one spare engine of 80 to 100 I.H.P.; in regular work one cylinder only of the twin engine is used, giving off 120 I.H.P. The current is generated by three Siemens dynamos, so-called 300-light; a fourth similar dynamo is in reserve. The working electromotive force is 350 volts. The current generated by the three dynamos is sufficient to keep eight cars running simultaneously.

This plan has been most largely adopted in America, where there are probably not far short of one hundred electric railways at work and projected. It has certainly the recommendation of cheapness, for a higher voltage is permissible, and consequently a smaller conductor with less loss of power than in the case of the third rail; this is more especially important for long lines. As an instance of what is being done, a railway of eleven miles length is now in course of construction at Richmond, Virginia, and forty cars are building to be worked upon it on the overhead system. Another instance is the railway at Scranton, Pennsylvania, which has been in successful operation about a year. It is $4\frac{1}{2}$ miles long; five cars carrying motors from 15 to 20 HP. are in use, and four cars with 25 HP. motors are being constructed, each of which will be able to draw two others; the cars carry 75 passengers each. The current is generated by two 100 HP. dynamos driven by two 180 HP. engines, one set being spare; the potential adopted is 600 volts. The overhead conductors are of copper 5–16ths inch diameter; the supporting poles are 100 feet apart, about 20 feet high, and about 6 inches diameter at the thick end; the return circuit is through the ordinary rails. The plant is also used for lighting the town. The potential generally employed in America for the longer lines is from 500 to 600 volts; and this is probably the limit to which it is safe to work. With this potential two 3–8ths inch copper conductors would serve to work twenty-five cars in parallel, the current per car averaging about

10 ampères. With a voltage as high as this the leakage on the third-rail system would be excessive.

Underground Conductor.—Perhaps the most important example of this plan is Mr. Holroyd Smith's electric tramway at Blackpool, which has been in successful operation for some two years. The underground conduit, Fig. 7, Plate 19, is somewhat similar to that of a cable tramway such as is working at the present time in Edinburgh and on Highgate Hill, London; but instead of the carrier being used to grip a running cable, it is made to rub along a stationary conductor. The cost of working is stated to be less than fourpence per car-mile; during one week in the season of 1886 there were 44,306 passengers carried at a cost of £45 for wages and fuel, which is less than one farthing per passenger.

Where an underground conductor is employed, the advantages of having no slit communicating with the surface of the street are so obvious, that an ingenious plan has been proposed by Mr. Frank Wynne for placing the conductor in a hermetically sealed conduit under the line. A small carrier, which acts as a contact-maker between the conductor and short sections of rails laid in the road, travels along the conduit, being actuated by a tiny electro-motor and by part of the same current which works the tramcar above it. An absolute synchronism between the tramcar and the carrier is obtained by a simple device. The short sections of rails are in circuit only whilst the car is over them.

A plan has been proposed by Messrs. Ayrton and Perry for making contact between the underground conductor and the section of rail underneath the car, by means of the weight of the car, which actuates an arrangement of levers that make the contact so long as the car is on that section. A plan has also been proposed by them for employing the attraction of a magnet fixed on the car and keepers fixed in boxes underneath the street. The contacts on the keepers are permanently connected with the underground conductor, and when lifted by the attraction of the magnet on the car they make connection with a section of rail, putting the motor in circuit.

Storage Batteries.—Storage batteries on the car have not as yet been much used, though many experiments have been made from

time to time. The problem was first attempted by Mr. Reckenzaun, who has done much to perfect the plan. The difficulty is that, if the accumulators are made light, their depreciation is high; while if they are constructed with a thoroughly serviceable make of cell, their weight is very great. The first cost of the cells is also somewhat prohibitive, and their depreciation is high. A trial of this plan on a practical scale is now being made by Mr. Elieson on the North Metropolitan Tramway in London. The storage cells are placed on a separate locomotive car. The motor turns itself round on an upright pivot, by means of a bevel wheel on the armature shaft, gearing with a circular rack fixed on the floor of the car; and the revolution of the motor is transmitted to the axle of the car through mitre gear. Trials are also being made in Brussels, in Philadelphia, and in other places; but there appear to be no very reliable data as to the cost of working. The plan has been unsuccessful in the past, owing to the use of inefficient motors and gear, which require of course an increased size of battery in proportion to their inefficiency; the imperfection of the secondary batteries employed, as pointed out, has also prohibited success. With motors, speed-reducing gear, and secondary batteries all improved, the experiments now being made bid fair to demonstrate the successful working of tramways by electricity in crowded thoroughfares.

Ordinary Rails as Conductors.—The short electric railway of Mr. Volk at Brighton on this system is interesting as being one of the earliest in use in this country. The expenses amount to twopence per car-mile, being made up as follows:—

Gas for engine	1·11	penny.
Wages	0·70	,,
Oil and waste	0·07	,,
Repairs	0·12	,,
Total per car-mile	2·00	pence.

The total car-miles per annum are stated to be 47,000, and the depreciation at 10 per cent. on the £3000 cost of construction is therefore equal to $1\frac{1}{2}$ penny per car-mile, thus bringing up the total

cost to $3\frac{1}{2}$ pence per car-mile. Several similar railways are now working or contemplated in seaside towns.

Cost of Working.—From these instances it will be seen that, taking into consideration the fact that the machines here employed are not so efficient as those now being made, an electric tramway may be worked for about threepence per car-mile; and as the cost of horses is from sevenpence to ninepence per car-mile, the importance of electric propulsion for tramcars and short railways is very evident. At the Antwerp Exhibition in 1885, when electric locomotion was beginning to receive consideration in its commercial aspect, a series of trials extending over four months on five different kinds of tramway motors resulted in the first place being assigned to the electric car, in competition with the four following plans:—the Krauss and the Wilkinson locomotives separated from the car, the Rowan engine and car combined, and the Beaumont compressed-air car. The results of these trials are given in Table 3:—

TABLE 3.—*Trials of Tramway Motors at Antwerp Exhibition*, 1885.

Description of Motor ...		Electric.	Rowan.	Wilkinson.	Krauss.	Compressed-Air.
Train-miles run, total ...		2,359	2,617	2,473	2,458	2,259
Consumption of Fuel	total ... lbs.	14,786	14,498	22,000	22,726	90,420
	per train-mile, lbs.	6·16	5·42	8·82	9·10	39·48

Notwithstanding that the use of electricity for heavy railway traffic has been predicted, the author thinks that, so long as the electricity is generated by dynamos driven by steam-engines, steam locomotives will not be discarded in favour of electricity for long distances. But for light railways and suburban lines, underground or overhead, where the use of a steam engine is a nuisance, there can be little doubt that electricity must be largely adopted in the immediate future, as the number of such railways already constructed and in course of planning is now between one and two hundred.

Underground Haulage.—Electricity has been applied to haulage in various mines. A locomotive car, worked by a current sent

through a conductor fixed along the side or the roof of an underground road, could be employed economically wherever the traffic is large and the distance considerable; but there is the objection of requiring a heavy locomotive car, in order to get sufficient tractive power for starting a train of tubs.

In a colliery at Zaukeroda, near Dresden, power is generated above ground by a vertical engine having 10-inch cylinder with 8-inch stroke, which drives a Siemens dynamo. The current is led to the shaft, which is about 60 yards distant, by two bare copper wires; then down the shaft to a depth of 120 fathoms by well insulated conductors, to the ⊥ irons, which run along the roof of the wagon way and form the contact rails, as shown in Plate 21. The current is picked off these rails by sliding contact-pieces attached by a rope to the locomotive, and is led to a switch, which can turn the full current either through the motor, or first through reducing resistances and then to the motor. A controlling switch with a seat for the driver is placed at both ends of the locomotive, so that perfect control of the speed and of the starting and stopping of the motor is provided. The length of the line is about 700 yards, and the gauge is $22\frac{1}{4}$ inches. A train consists of about fifteen tubs, each carrying 10 cwts. of coal; and the locomotive weighs rather over 30 cwts. The journey takes from three to five minutes, the speed varying from 5 to 7 miles per hour. The plant cost a little above £800, including steam engine, dynamo, motor, locomotive car, conductors, and accessories; it has been working successfully since 1882, and was supplied by Messrs. Siemens and Halske, by whom several other mines in Germany have since been similarly furnished. The working cost of hauling 660 tubs per day of sixteen hours is given by Mr. F. J. Rowan as follows:—

	s.	d.	s.	d.
Driver's wages	5	3		
Steam	2	3		
Engine-driver at surface	3	$1\frac{1}{2}$		
Lubricating, &c.	1	$1\frac{1}{2}$		
			11	9
Interest and depreciation at 15 per cent. per year of 300 working days .			8	$1\frac{1}{2}$
Total working cost per day			19	$10\frac{1}{2}$

For the output of 660 tubs or 330 tons per day this amounts to only about three farthings per ton.

TABLE 4.—*Electric Railways in Europe and America.*

	Place, and mode of working.*		Length of line.	Rolling Stock.	Cost of working.
		*	Miles.		Pence.
EUROPE.	Lichterfelde, Berlin	R	1·5	2 cars	
	Brighton	R	1	2 cars	1·92*d.* per car mile
	Moedling-Hinterbruchl	O	2·8	12 cars	3·42*d.* per car mile
	Frankfort-Offenbach	O	4·5	14 cars	3·83*d.* per car mile
	Zaukeroda colliery	O	0·45	1 locom. 16 wagons	0·77*d.* per ton
	Hohenzollern mine	O	0·47	1 locom. 15 wagons	0·50*d.* per ton
	Portrush	Th	6	4 cars	2½*d.* per car mile
	Bessbrook and Newry	Th	3	8 cars	4*d.* per train mile
	Blackpool	U	2	10 cars	less than 4*d.* per car mile
	Brussels	S	...	5 cars	
	Hamburg	S	...	2 cars	
AMERICA.	Baltimore, Md.	Th and O	2	6 cars	16*s.* 8*d.* per car per day
	Los Angeles, California	O	3	8 cars	
	Port Huron, Michigan	O	4	8 cars	
	Windsor, Canada	O	2	2 cars	16*s.* 8*d.* per day for power
	Highland Park, Detroit	Th	3½	2 cars	3*s.* 2½*d.* per day for fuel
	Dix Road, Detroit, Mich.	O	1¾	4 cars	
	Appleton, Wisconsin	O	4½	8 cars	
	Scranton, Pennsylvania	O	3¼	3 cars	
	Denver, Colorado	U	3½	7 cars	6*s.* 2*d.* per day for fuel
	Montgomery, Alabama	O	11	18 cars	50 per cent. less than horse and mule traction
	Kansas City, Missouri		...	...	
	Orange, New Jersey	O	½	1 car	
	Boston, Mass. (short line in sugar refinery)	O	...	1 locom. 3 cars	

* O = Overhead conductor. R = ordinary Rails. S = Storage batteries.
Th = Third rail. U = Underground conduit.

Telpherage.—The plan of transporting material in skips on overhead wire-ropes by means of electricity, introduced under this name by the late Professor Fleeming Jenkin of Edinburgh, and illustrated in Plate 22 from a diagram kindly lent by Professor Ayrton, has not so great a field for its use in this country as it may have in less populous regions, because our roads are good, and railways generally near at hand, and we have abundance of water carriage. But in places where material has to be conveyed across hilly districts or over bad roads to the railway or water, it will be found more useful. It has been employed with considerable success for the past two years at Glynde near Lewes for transporting clay to the railway over a distance of 1600 yards; 270 tons are carried weekly at 7½*d.* per ton. In our larger cities a modification of this plan might advantageously be applied to alleviate the heavy street traffic. In the place of wire-ropes, stiff girders might be used, the cars being suspended from wheels running along a rail or rails fixed on the girder. Such a railway would be economically constructed, in comparison at least with the expense of constructing an underground railway; and it would not have any great effect in obstructing the light from the streets, as is the case with elevated railroads for steam locomotives.

A general idea of the present position of electric locomotion in Europe and America is furnished by Table 4 (page 97), which is an abbreviation of one compiled in May 1887 by Mr. T. C. Martin, President of the American Institute of Electrical Engineers.

III. ELECTRIC LIGHTING.

Of the four branches of electric engineering dealt with in this paper, electric lighting is the one which up to the present has received most attention, called forth the largest outlay of capital, and produced the most beneficial results, if not to so great an extent in this as in other countries.

Artificial illumination may be considered in the three aspects of comfort, convenience, and economy.

As regards *comfort*, electric lighting proves itself superior to all other methods of illumination. For indoor lighting, the incandescent light may be utilised and toned down to suit almost any requirement. It may be brought near to any object requiring illumination, without occasioning the least inconvenience from heat or dazzle; or it may be far removed in the ceilings or cornices, without risk of fire or of injury to the decoration. In short it can be used in any position or for any purposes of illumination for which gas, oil, or candles are available, and for a great many for which they are not available. For outside illumination and large enclosures, the arc light gives a brilliancy and cheerfulness altogether unattainable by any reasonable expenditure of gas or oil.

The *convenience* of the electric light has caused it to be highly appreciated, when it is found that by the mere pressing of a button a light is instantly obtained, which can be shaded over in any manner, without danger of setting fire to the fabric forming the shade. It also does away with the constant cleaning of globes or trimming of lamps.

In respect of *economy*, the electric light does not as yet hold out the same decided advantages that it does in the other two respects just considered. In incandescent lighting, the cost of distribution is still heavy, though by increasing the electromotive force and the efficiency of lamps it is being much reduced. In arc lighting, the difficulty of subdividing and of reducing the amount of light given by one arc-lamp renders it expensive for general out-door street illumination, as compared with the present low prices of gas and oil. For the lighting of main streets and railway stations, or other places where a concentrated light is required, the arc light is beyond question far cheaper than gas; and its cost per candle-power is but a very small fraction of that of gas. As the use of electric lighting extends, the cost of working becomes reduced; installations which four years ago cost fourpence per arc lamp per hour are now costing only twopence. The chief saving has been in the items of carbons and attendance, though the increased efficiency and durability of the apparatus have also greatly contributed to the reduction: four years ago 11-mm. or 0·43-inch hard carbons cost 4*d*. per foot; they can now be obtained for $1\frac{1}{4}$*d*. per foot, or less than one-third their former cost.

The following figures supplied by the North British Railway respecting the actual cost of working their electric lights at the Waverley Station, Edinburgh, are interesting as showing how much cheaper it is becoming. The installation is worked by their own staff, and consists now of forty Brush arc-lamps, supplied with a current of 10 ampères by a No. 8 Brush dynamo, which is driven by a semi-fixed engine.

July to December 1884, *thirty-three arc-lamps*, 41,884 *lamp-hours.*

	£	*s.*	*d.*
Wages	165	13	9
Repairs	47	2	6
Carbons	125	15	11
Coal	65	19	11
Oil, stores, &c.	27	15	0
Interest and depreciation at 10 per cent.	52	2	2
Equal to **2·77** pence per lamp-hour.	£484	9	3

July to December 1886, *thirty-nine arc-lamps*, 55,068 *lamp-hours.*

	£	*s.*	*d.*
Wages	195	17	6
Repairs	78	9	6
Carbons	62	17	3
Coal	23	14	1
Oil, stores, &c.	8	15	2
Interest and depreciation . . .	41	10	6
Equal to **1·79** penny per lamp-hour.	£411	4	0

In conjunction with these arc lamps they are running 148 Brush Victoria incandescent lamps, distributed in the refreshment and waiting rooms, and throughout the whole of the suburban station. For these the total number of lamp-hours for the half year was 171,251, and the cost was £83 9*s.* 9*d.* including all contingencies, equal to 0·12 penny per lamp-hour. There were 113 lamps renewed, which shows an average life per lamp of 1,515 hours.

Local Conditions.—The cost of incandescent lighting is especially variable, and affected by the local conditions of the installation. The chief of these are firstly the average number of hours of lighting each lamp, and secondly the average distance of the lamps from the generating station. In the diagrams, Figs. 2 and 3, Plate 17, are drawn curves which have been constructed by the author to show the relation between these conditions and the cost per lamp-hour. Where the conditions are favourable, incandescent lighting can already compete with gas; and in a number of installations which have been superintended by the author a large saving is being effected. The following figures kindly supplied by Messrs. George Jager and Son show that the yearly cost of lighting their sugar refinery at Leith has been reduced from £347 with gas to £204 with incandescent lamps, being a saving of £143 per annum. The average life of the lamps is about 1400 hours each. The installation consists of 180 Brush Victoria lamps of 17 and 10 candle-power, supplied by a self-regulating Victoria dynamo, which is driven off the shaft that drives the centrifugal drying machines. The dynamo has been running night and day since it was started two years ago, without failure; it is started on the Monday morning, and runs continuously without stoppage till the following Saturday afternoon.

	£	*s.*	*d.*	£	*s.*	*d.*
Previous average cost of Gas lighting per annum .	332	13	4			
Part of plumber's time	15	0	0			
				347	13	4

Cost of Electric light, May 1886 *to May* 1887.

	£	*s.*	*d.*	£	*s.*	*d.*
Lamp renewals	46	9	8			
Oil, waste, sundries	17	5	0			
Coal at 3 lbs. per HP. per hour, 40 tons at 6*s*. . .	12	0	0			
Repairs, including men's time attending dynamo .	36	5	3			
Depreciation at 10 per cent.	33	16	0			
Gas consumed on Sundays, and when engine is standing	58	4	5	204	0	4
Saving per annum by Electric lighting . . .				£143	13	0

TABLE 5.

ELECTRIC CONDUCTORS.—*Sectional Area, Cost, and Potential Fall.*

Cost of Conductors.	£100 per ton = 10·71*d*. per lb.			£150 per ton = 16·07*d*. per lb.			£200 per ton = 21·43*d*. per lb.			£250 per ton = 26·79*d*. per lb.		
Cost per year per electrical horse-power.	Area per 100 ampères.	Cost per 100 yards.	Potential Fall per 100 yards.	Area per 100 ampères.	Cost per 100 yards.	Potential Fall per 100 yards.	Area per 100 ampères.	Cost per 100 yards.	Potential Fall per 100 yards.	Area per 100 ampères.	Cost per 100 yards.	Potential Fall per 100 yards.
£	Sq. Inch.	£	Volts.	Sq. Inch.	£	Volts.	Sq. Inch.	£	Volts.	Sq. Inch.	£	Volts.
½	0·04576	2·378	5·3231	0·03736	2·912	6·5194	0·03235	3·362	7·5279	0·02894	3·759	8·4165
1	0·06471	3·362	3·7640	0·05283	4·118	4·6099	0·04576	4·755	5·3231	0·04093	5·316	5·9514
10	0·20463	10·633	1·1903	0·16708	13·023	1·4578	0·14470	15·037	1·6833	0·12942	16·812	1·8820
20	0·28939	15·037	0·8417	0·23629	18·417	1·0308	0·20463	21·266	1·1903	0·18303	23·776	1·3308
30	0·35443	18·417	0·6872	0·28939	22·556	0·8417	0·25062	26·046	0·9718	0·22416	29·120	1·0866
40	0·40926	21·266	0·5951	0·33416	26·046	0·7289	0·28939	30·075	0·8417	0·25884	33·625	0·9410

In the United States there is hardly a city or town of 20,000 inhabitants which has not a central station for arc or incandescent lamps; and many towns of 3,000 to 4,000 are supporting them also. On the Continent large central stations for electric lighting are already in operation in competition with gas; but there the price of gas is generally two or three times what it is in this country.

If the power is to be generated by dynamos and used direct, the cost of distribution on a large scale will probably never be reduced as low as with the existing gas supply; seeing that an efficiency of 95 per cent. can now be obtained with the dynamo, and that steam engines are not likely to be materially improved. It is therefore in the lamps that improvement is to be looked for, by making them with a higher resistance and greater efficiency. From the curves in the diagram, Fig. 3, Plate 17, it will be seen how great an effect the voltage has on the cost of working the distant lamps.

The accompanying Table 5 (page 102), which is an abbreviation of one previously constructed by the author,* may be interesting here as showing how the economical sectional area of conductor and the economical loss of potential vary for the different conditions of amounts lost in interest and depreciation on the conductors, and in horse-power wasted in overcoming the resistance of the conductors. The question of conductors is one which must be left to a very great extent at the discretion of the engineer, in view of what are likely to be the requirements of each individual case; but when the conditions have been settled, Table 5 is useful in showing at a glance the size and cost of the conductor, and the ensuing loss of potential.

Transformers.—These are at present receiving a large amount of attention. By their means small high-tension currents of electricity, sent from a distant generating station along a small conductor with a comparatively small percentage of loss, can then be converted into large low-tension currents for the supply of ordinary incandescent lamps. In some arrangements of these transformers the loss in conversion is not more than 5 per cent. Unfortunately

* See "The Electrician," 12 April 1884, page 522.

the alternating system, which has thus far been adopted, cannot be used with satisfaction for driving motors doing practical work or for charging storage batteries. The continuous-current transformer has certainly the advantage in respect to the supply of power and to the charging of storage batteries; but it is a question whether the disadvantage of having to keep it continually in motion will enable it in town lighting to compete with the alternate-current transformer. The latter is employed in the Grosvenor Gallery central station in London. Some idea of its importance may be formed from the fact that the Westinghouse Co. have already in America over 100,000 lamps at work on this system, although it is not yet so much as two years since they adopted it. Notwithstanding that the use of transformers enables a great saving in copper to be effected, more especially where the lamps are scattered as in suburban districts, yet it is to be remembered that the insulation of underground conductors forms a very important item in their total cost. The installations already at work are all worked with overhead conductors, with the one exception at Eastbourne; so far as the author is aware there are no practical data to establish the general applicability of the transformer system for the lighting of large and thickly populated towns where underground conductors may alone be tolerated. The loss owing to induction will also be vastly greater with underground conductors however carefully installed.

Secondary batteries charged in series by a high-tension current and discharged in parallel circuit have been tried experimentally; but their practical application is not known to the author. At the same time, now that transformers are becoming more used, strenuous efforts are being made to introduce this system of secondary batteries; and if it can once be demonstrated to be economical, there can be little doubt that it would have a large field of application. Its great merit is of course the reduction of risk of the light failing.

It should be borne in mind by electric-light companies that the supply of incandescent lamps is not to be their only source of revenue; but as already pointed out, the supply of current should be

of such a nature that it may be employed for as many purposes as possible. By the use of efficient boilers and engines and properly constructed continuous-current dynamos, a central station can be so constructed as to be no nuisance whatever, provided proper precaution be taken in selecting the site. In large towns it will not be necessary to extend the conductors very far before a demand will be met with sufficient for occupying an engine large enough to be economical. Above a certain size the cost of working a steam engine becomes practically constant for any increase in size; so that, instead of working from one large central station over a very large area, it is found better to work from smaller stations over smaller areas. The cost of attendance will thereby be increased to only a small extent, because one man cannot fire more than two boilers; therefore when more boilers are required, it is preferable to work them at another station with another fireman. At Leamington an extensive central station is now at work, and the cost of the undertaking is about £30,000. The Bradford corporation have recently voted a sum of £15,000 for erecting a central station in their town. Both of these are instances of direct supply, without transformers or secondary batteries.

IV. Electric Metallurgy.

This branch of electrical engineering bids fair to become speedily of the highest interest to engineers.

Smelting.—The electro-chemical separation of ores on a commercial scale by the electric furnace has but recently been put to the test, chiefly in obtaining aluminium from corundum, which is its richest ore, being anhydrous alumina. Sir William Siemens first turned his attention to the subject, but his death occurred before he had perfected his invention. It was taken up by Messrs. Cowles, who with the assistance of Professor Mabery have devised a furnace, in which by the passage of powerful currents the refractory ore is successfully reduced. The furnace is built of fire-brick, and lined with powdered charcoal to withstand the intense heat; it is in the form of a box, 5 feet long, 12 inches wide, and 15 inches deep. Current is

conducted through the walls and into the ore by means of a number of carbon rods, 3 inches diameter and from 2 to 3 feet long. The positive and negative carbons are introduced from opposite ends, and nearly meet in the centre. The ore, mixed with charcoal and granulated copper, is put in so as completely to surround and cover the carbons. The furnace thus charged is closed with a layer of charcoal and a lid lined with firebrick; without the protection of some such refractory material as charcoal the intense heat causes the firebricks to run. When the furnace is ready, the current with an electromotive force of 50 volts is turned on, and is gradually increased up to some thousands of ampères. In a few minutes the metal is melted around the electrodes; and these are then moved farther apart, until the current passes through the entire charge, and the whole is in a molten condition; the corundum becomes gradually deoxidised, the aluminium combining with the copper, while the oxygen with the carbon escapes as carbonic oxide; about five hours suffice to complete the reduction. Current is supplied by large Brush dynamos, one of which is shown in Plate 23. This machine was specially constructed for the work, and is capable of giving out 300,000 watts, or over 400 electrical horse-power. Its weight is nearly 10 tons; 5,424 lbs. of copper are wound on the field magnets, while the armature has 825 lbs. of copper on it. Works already in operation at Lockport, U.S., have a capacity of 6,000 lbs. per day; and the cost of the aluminium-bronze so made is expected to be less than 1*s.* 8*d.* per lb., while Mr. Cowles anticipates the price being reduced to 8*d.* per lb. Works have also been started at Stoke-on-Trent, where a 500 HP. dynamo has been fixed for generating the current; the potential is 60 volts.

Another electric furnace has been devised by Dr. Kleiner of Zurich, in which cryolite, a double fluoride of sodium and aluminium, is similarly treated.

When it is remembered that the metal aluminium, in addition to many other good qualities, possesses great strength with only one-third the weight of iron, the importance of obtaining it at a reasonable cost will be readily appreciated; it would undoubtedly cause a great revolution in engineering construction.

Welding.—The process of welding by electricity, introduced by Professor Elihu Thomson, is similarly based upon the passage of a powerful current between two electrodes. In this case the two pieces of metal to be welded form the electrodes; they are brought together into close contact, and as soon as the current is sent through the joint its resistance causes intense heat until the weld is perfectly completed. The process is almost instantaneous, and the heating occurs only at the joint; tempered steel can be thus welded without in the least affecting its hardness.

Another plan of electric welding has been introduced at St. Petersburg by Dr. Bernardos, in which the heat necessary for fusion is caused by an arc. The current is conducted to the weld by means of a carbon rod, which is connected by a flexible cable with the positive terminal of a dynamo or battery, while the metal to be welded is connected with the negative terminal. The action of the arc set up by the flow of current from the carbon to the metal may be likened to that of the blow-pipe flame, except that the heating is more intense and sudden, and is therefore more local. The reducing action brought to bear on the metal keeps it clean and unoxidised.

Discussion.

Mr. Geipel exhibited a collection of photographs illustrating the Bessbrook and Newry and the Frankfort Offenbach electric tramways, and also the application of electricity to underground haulage in collieries &c.

Mr. John P. Fearfield, while agreeing with the greater part of the paper, wished to point out that, in addition to the cost of the plant and the cost of running it, there was also an important item of cost of repairs to be considered. To the cost of dynamos and

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motors, referred to in page 77, he considered ought to be added the cost of repairs to brushes, commutators, and armatures. Having himself erected several dynamos constructed by one of the best makers in England, of which ten or eleven were now running of about 9 electric HP. each, he had found that they sometimes did not work as they should, even with ordinarily good engine-drivers who had been fairly trained to the work: not electrically trained, but men who knew how to pack the glands, to oil the joints, and to keep them clean. He desired to draw the attention of the best electricians to the fact that the armatures were often a source of discomfort. Besides having four dynamos running in his lace-machine works near Nottingham, he had also put down eight or nine in other works; and in his own works he had found that the annual cost of renewal of the armatures ranged from £4 per armature up to £7 or £8, and in one instance up to £10, the armature itself costing only £18 at first. The renewals were necessitated by the wearing down of the phosphor-bronze commutator, which if oiled too much fired from the brushes; and therefore it was found that the electric current cut the barrel of the commutator irregularly, and it had to be put in the lathe again and trued up. Or else, if it ran dry from insufficient oiling, the brushes, whether wire or split plate, cut it down, and the copper dust got inside the armature, and could not be kept out; and when the armature was sent to be repaired, it was found that the insulation had been destroyed on several sections, and the armature had to be re-wound. This had been his own unfortunate experience with several of these armatures, which he had applied not only to transmission of power but also to electric lighting.

Where mention was made in page 80 of a 4-inch belt through which certain machinery was driven from a 6-HP. motor, he should be glad to know also the speed of the belt; for it would drive practically almost anything, provided the speed was high enough, because the power simply depended on the speed. With transmission of power he had himself had little to do, but a good deal to do with electric lighting in a small way; and he had found the cost vary excessively. In a small plant that he had put up under most favourable conditions, the cost was as high as if an equal amount of

light had been kept up by gas charged at not less than seven shillings per thousand cubic feet; whereas in a larger installation that he had also put up, which ran practically night and day, the electric lighting over a period of four years had actually cost him only 2*s.* 1*d.* for an equal light given out by one thousand cubic feet of gas. These comparisons were based upon the price of 2*s.* 4*d.* per thousand cubic feet which was charged for gas supplied to his own works at a distance of eight miles from the Nottingham gas works. Although engineers doubtless knew better, it was a very common mistake for people to fancy that they were going to get electric lighting for practically no higher cost than gas, and yet with ten times the light of gas. Also no consideration whatever seemed to be bestowed upon the fact that electric lighting gave a far better light than gas, a far purer atmosphere, and no dirt. In one of the lace-making rooms in which he had introduced it, where there were ninety girls at work, he had been congratulated by the factory inspector on the difference it would make to their health. He had further been congratulated by the proprietor of the lace works on the absence of dust upon the lace, and on the consequent diminution of the loss which would be sustained in the shape of soiled stock. He drew attention to this point because he was confident that in the almost immediate future mechanical engineers would have to deal largely with the electric light and with the electrical transmission of power. In illustration of the ease with which the electric light could be fixed, he might mention the case of an evening party given close to his works, where a few lights were wanted in the front of the house. Within two hours twenty-four lights were fixed there by two men, one a fitter, the other a man who attended on dynamos. The lights remained there two nights, and were then taken down again in an hour and a half. This was enough to show that the electric light could be fixed far more easily than any other light of which there was any experience hitherto.

With regard to armatures and repairs, he mentioned that, during the time when the Colonial and Indian Exhibition was open in 1886, he received a telegram from one of the largest dynamo makers in London to send immediately half a dozen armatures of a certain size.

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It turned out that in hanging the arc-lamps in the Exhibition care enough had not been taken about their insulation, and in consequence, with armature after armature that was put in, the wires were immediately burned. Although there was too much speed on the engine, the voltage requisite to drive the lamps could not be attained, because before it was raised to its normal strength the wires were burned down in the armatures. This showed that the men employed in such work would have to be trained electricians as well as engineers.

It had been stated in page 92 of the paper that 600 volts was probably about the limit of tension to which it was safe to work the electric current for tramcars. In a lecture lately given by Mr. Preece * it was stated that, although the powerful currents employed in electric lighting were supposed to be very dangerous, they were not so in reality. No doubt if anyone deliberately passed such a current through his body, the result would be fatal; but no current yet produced was so dangerous as a steam boiler. Many engineers still remembered the time when 10 lbs. pressure per square inch above the atmosphere was considered an excessive and dangerous pressure in a steam boiler; but now locomotive boilers were carrying 140 lbs. pressure, and marine boilers 160 lbs. with safety. Electricians therefore could say with perfect truth that, with the same amount of knowledge in electrical matters as in regard to steam boilers, a current of 10,000 volts could be conveyed along a wire as safely as a pressure of 160 lbs. was now carried in a steel boiler. Within the next three years he considered that 600 volts would be reckoned as one of the low tensions of the past; and there was not the least doubt that much higher tensions would have to be employed, on account of the one difficulty which had to be faced of getting a tension at the end of a conductor closely equal to that at the beginning. The same thing had to be done with steam and with hydraulic pressure, and it would ultimately come about in electrical conductors. It was simply a matter of sufficiently high insulation and cost of conductors.

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* Journal of the Society of Arts, 13 January 1888, page 177.

The President asked for some further explanation as to the cost of gas compared with that of electric lighting.

Mr. Fearfield said that the Nottingham gas was delivered within a radius of eight miles from the gas works at 2*s.* 4*d.* per thousand cubic feet. In a factory where he had erected a small electric-light installation driving usually only thirty or forty lights, there was 95 lbs. steam in the main boilers day and night, Sundays included. For lighting by electricity during the hours only that suited the convenience of the works, the cost was nearly as high as if the same amount of light had been supplied by gas charged at no less than 7*s.* per thousand cubic feet. On the other hand, in the most favourable installation of which he had any knowledge, the electric light had cost no more than if the same amount of light had been obtained from gas charged at only about 2*s.* 1*d.* per thousand cubic feet. In other words, for the same absolute candle-power of light distributed over the works, the cost with gas would be 2*s.* 4*d.* per thousand cubic feet, while with the electric light it was only 2*s.* 1*d.* in the best case, but in the other case it rose to as much as 7*s.* Thus in one instance the electric light was 11 per cent. cheaper than gas, while in the other it cost three times as much as gas. It was simply a question of the size of the plant and the convenience of engine power and of driving. The higher cost arose from running an installation put down for not more than only 55 or 60 lamps of 16 to 20 candle-power each, while the lower cost resulted from running 300 lamps of 18 to 20 candle-power each. In the latter case the installation was really large enough for 500 lights, but there were never more than 436 running at once. Thus the larger the installation, the lower was the cost of lighting by electricity.

The President said that a few letters on the subject of this interesting paper had been received from gentlemen who were not able to be present, and he thought it would be well for them to be read at the present stage of the discussion. One was from a member in Russia, whose example in communicating what he had there witnessed would he hoped be followed by other members who were

(The President.)
abroad and had the opportunity of seeing what was going on in other countries.

Mr. Henry Barcroft wrote to ask about the Victoria motor—mentioned in page 78 as possessing a practically perfect power of self-control—whether this power was sufficient to prevent running away in case of short-circuiting. Also what was the plan adopted on American railways for the electrical connection of the rails; when so many roads (page 92) were now actuated there by electricity, this subject must presumably have received attention.

Mr. Albion T. Snell wrote respecting the power transmitted by electricity to Solothurn, which was given in page 87 as 50 horse-power with a commercial return of over 70 per cent. The total power in the water he believed was only 40 H.P., and that transmitted was about 20 H.P., which would give an efficiency of only 50 per cent.

Mr. Sydney F. Walker wrote that he agreed with the author (page 77) in looking forwards to the time when electric transmission would take the place of shafting and belts in factories; but he saw no reason why 10 per cent. or even 5 per cent. loss should be allowed in the conductors. By the time electrical transmission was practically adopted in factories, probably 1 per cent. would be ample to allow for loss in the conductors with full load in the largest factory.

In reference to the 6-HP. electro-motor mentioned in page 80 as doing work under which a 10-HP. steam engine had sometimes come to a standstill, he enquired how the measurement had been taken. Was it a nominal 6-HP. motor developing 10 HP. actual at the shaft, in comparison with an engine giving 10 HP. indicated?

With regard to the self-regulating motor to run at constant speed (page 78), it appeared to him that the only condition under which a shunt-wound motor could be practically self-regulating at constant speed was the same as that under which a shunt-wound dynamo could be practically self-regulating at constant electromotive force—

namely that its armature resistance was very small in proportion to the largest current passing through it; and this meant that the machine must be constructed very much larger and heavier than would otherwise be necessary. The self-regulating motor at constant speed would undoubtedly be the compound-wound motor, as had been shown by Mr. Kapp; and for the following reasons. The work which a given motor would do depended upon its speed and upon the current passing through it. With the speed constant, the current was the only possible variable; and it could only be varied by altering the number of lines of force passing into the armature; and this again could only be accomplished, so far as was at present known, by causing the working current to effect that alteration, that is, by compound winding.

With respect to the transmission of power in mines, before much was done in that direction he thought that two subsidiary problems would have to be dealt with:—namely the insulation of the dynamo and motor, and the loss involved in reducing the speed from the motor shaft. At the present time dynamos and motors were not properly insulated for high tensions; and it was well known that economy of transmission by electricity and diminution in the size of the conductors depended upon the use of high tensions. The accidents which had taken place with high-tension machines had in his opinion been due in many cases to the want of efficient insulation of the dynamo. The other problem was equally important; for at the present time electro-motors ran usually at from 800 to 1,000 revs. per minute, and only in a few special cases as slow as from 350 to 400 revs.; while pumps ran at only from 25 to 60 revs. per minute, and other apparatus, such as hauling engines, also at a very slow speed. It appeared to him therefore that, before electro-motors could be much used in mines, their speed would have to approximate very much more closely to that of the machinery they were required to drive, or at least to that of the steam and other motors in use at the present time.

Electric lighting he believed was now firmly established as by far the best method of illumination for the surface, pit bottom, and main roads of collieries; and it would probably in course of time

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(Mr. Sdyney F. Walker.)
be taken to the face of the coal. The principal reasons for its adoption were its greater safety, convenience, and economy. The cost of lighting a colliery by means of electricity was in his own experience from one-fourth to one-twelfth of the cost by gas.

Mr. Alfred S. Bolton wrote that the works for carrying out the Cowles process of electric smelting (page 105) at Milton near Stoke-upon-Trent were about completed, and the electric leads were now being attached to the furnaces, so that in the course of a few days he hoped to get a start made. If by this means ferro-aluminium and aluminium bronze could be produced cheaply, it would be a great boon to many industries.

Mr. Thomas Urquhart, locomotive superintendent of the Grazi and Tsaritsin Railway, Borisoglebsk, South Russia, sent the following account of the electric welding and other operations which he had witnessed in the middle of December last at the electrical welding works of Dr. Bernardos in St. Petersburg.

On entering the works the visitor is supplied with one of the small wooden hand-frames, about six inches square, containing two plates of darkened stained glass, which are necessary for protecting the eyes from the very intense light evolved during the operations. One of these frames is held by the operator in his left hand, while with his right hand he traverses the carbon pencil along the seam or joint to be welded. The carbon pencil used was about $\frac{3}{4}$ inch diameter, and such as is used in electric arc-lamps. A couple of specimens of welding and perforating done in the writer's presence are exhibited, and are illustrated in Figs. 17 to 19, Plate 24.

The sample of welding, Figs. 17 and 18, consists of two small pieces of bar iron, $\frac{3}{8}$ inch square and about 3 inches long, welded together longitudinally. These two pieces were laid side by side on an anvil, the carbon pencil was traversed along the joint, and the surface metal of both pieces was immediately fused together; the pieces were then turned over, and the operation repeated on the other side. On returning to Borisoglebsk the writer had this weld tested, by making a cut with a chisel on one edge and then doubling

the piece up transversely, so as to lay the joint open. It was then found that the weld was simply skin deep, as shown in Fig. 18, and that daylight could be seen through endways between the two pieces of iron: thus proving that, although joined together at surface along each side, they were not thoroughly welded throughout the thickness of the iron. It was also noticed by using a magnifying glass that the fused part of the iron seemed deteriorated, having a burnt appearance. It would be premature to express any positive views on this new process; but the writer may mention that in a number of fractures in the welds which he has seen he has invariably noticed a deteriorated or burnt appearance of the iron. How much less the tensile strength may be at the weld than in the solid metal, he has not yet learnt; it is reported that the tensile strength of the welded parts is equal in some cases to that of the solid metal, and in other cases is even greater. Pieces so welded and subjected to torsion showed a considerable deterioration of the metal. The temperature of the voltaic circuit is stated to be as high as 4850° centigrade or 8760° Fahrenheit. Analysis proves that the metals welded by this process undergo considerable changes in structure and in chemical composition. Meanwhile there seems no limit to the uses to which electric welding can ultimately be applied, although for the present it may be limited to light sheet-iron work only, or to light articles generally.

The other specimen exhibited, Fig. 19, Plate 24, is simply the end of a piece of sheet iron, less than 1-16th inch thick, and originally about 20 inches long. This end was submerged about a foot under water, the carbon pencil being also submerged. As soon as contact is made between the carbon pencil and the iron, a hole is melted through in a moment. All the holes in this sample plate were so made; and ultimately, by moving the carbon pencil across the plate, this end piece was cut off altogether. Very energetic ebullition takes place during the operation; and no eye protectors are necessary while fusing or welding under water. From this illustration it will be perceived in how many cases such an appliance will become of great use for subaqueous operations. The manager of the works mentioned that the application of this process was contemplated in

(Mr. Thomas Urquhart.)
Poland for cutting up an iron bridge under water into sections, so as to admit of raising each part separately; the bridge had had its abutments washed out last spring, and had fallen into the usually navigable channel, and no means had hitherto been devised for clearing away the obstruction; and it was thought this process of cutting it through by electric fusion might serve the purpose admirably.

The electric current is generated by a Siemens dynamo, and the whole current of 120 ampères at 175 volts is conducted from the dynamo to accumulators, because of itself it would not have ampères enough, while at the same time being of too high a potential. The total number of accumulators at present in the works and in working order is 490, which are arranged in 7 parallel rows or groups having 70 elements in each group; and each group of 70 elements is further subdivided into 14 sets, each containing 5 elements, and each of these sets is connected with the general distribution board. The number of elements to be used can be regulated according to the dimensions of the pieces to be welded. The same electric power is also used for lighting up the premises; and amongst the machine-tools the writer noticed one lathe driven by a small dynamo, which derives its electric power from the same main source, so that no transmission by shafting is required.

Mr. James N. Shoolbred, referring to the curves given in Fig. 3, Plate 17, for showing the comparative cost of working incandescent lamps at different distances and with currents of 50, 100, and 200 volts, remarked that a potential as high as 200 volts was at present very rare for electric lighting: certainly not yet in general use. There might have been some instances in which it was employed; and in that case it would be interesting to have some further information on this subject.

On the question of motive power, he quite agreed with the author that, although electric lighting was the branch which had so far received the largest amount of attention, motive power in the proximate future was the one which would certainly receive a more extended application; and probably a much larger amount of

current would be used in this direction than for electric lighting, since there were numbers of small industries which would make use of so cheap and cleanly a mode of obtaining motive power throughout the entire day, whereas electric lighting could be made use of during the hours of darkness only, and in many industries not at all during the summer months.

On the subject of the cost of electric lighting, a great deal of unnecessary confusion and mystification appeared to have been introduced during the last few years in the comparisons that had been made between electric lighting and gas lighting. The whole matter really resolved itself into a question of the rate of production; and electricity had hitherto been produced on such a very small experimental scale that it was out of all reason to compare it with gas, which was produced on a vastly larger scale. But even gas engineers he thought would admit that there was very little doubt that at equal rates of production electricity was produced more cheaply than gas. Both began with coal and ended with light. As far as lighting was concerned, the cost of conversion of coal, by consuming it under the boiler of the steam engine driving the electric generator, was practically less, requiring less capital and less working expenses, than its distillation in the gas retort. Put in that way, the case seemed so simple that even gas engineers themselves agreed to it in many instances.

The merits of alternate and continuous currents had been spoken of in page 104, in connection with transformers and the future of electric lighting. To his own mind the future of electric lighting lay very largely in the extension of central-station lighting, which was now just beginning; it would enormously reduce the cost of the supply of electricity, which, as the author had shown, was very much less now than it was even a few years ago. It stood to reason that, if all the various establishments which were at present distributed throughout a town could be concentrated in one generating station, the current could be produced at a much cheaper rate. In connection with transformers, the author seemed in page 104 to speak of alternate and continuous currents as though the use of the current were practically limited to lighting; but it appeared to himself and many

(Mr. James N. Shoolbred.)

others that the public authorities who had to supply the current would do wrong to limit its use to lighting. Even commercially it would be found that the motive power which could be supplied by a continuous current would be so largely used that it would be folly simply to confine the production to an alternating current which could be used only for lighting purposes, but which it would be almost impossible to use either for motive power or for storage batteries. A great number of so-called central installations were at present being laid down, which would be fitted simply for lighting; but he thought it would not be very long before it would be discovered that in applications of this kind alternate currents were not the ones which were suited for general use. This question as to the suitability of alternating and of continuous currents had not now cropped up for the first time. Some years ago a difficulty had presented itself with regard to the use of a number of arc-lamps in series, and it had then been stated that it was impossible to get over it except by the use of alternating currents. In using a large number of arc-lamps no one now dreamed of falling back upon alternating currents; they had simply been an expedient for the time being. Continuous currents would probably solve the question again, and get over the present difficulty in connection with transformers. As regarded continuous-current transformers, there appeared to be certain difficulties at present; but these would no doubt be got over when the requirements of electricity demanded.

In connection with the figures given in page 101 as to the cost of lighting by electricity Messrs. Jager's sugar factory at Leith, he might mention as having come under his own experience a similar installation on a larger scale which he himself had designed and put up, commencing eight years ago at Messrs. Tate's sugar works in the east end of London. They began with arc-lights; then they had a larger number of arc-lights; and eventually, when the incandescent light came to the fore, they adopted it, and they had now extinguished all their gas lights, although their works were alongside the Silvertown gas works. Their demand for lighting was considerable, as they employed a thousand hands, and worked night and day, just as Messrs. Jager did. So satisfied were they

that the electric light was cheaper than gas, that they had extended it to another establishment of theirs at Liverpool, where also they employed a thousand hands. In both cases the price of the gas was about 2*s.* 10*d.* per thousand cubic feet; and he was informed by Messrs. Tate that the cost of electric lighting was considerably less. That was a commercial test in a trade in which employers could not afford to throw away money. It was the practical result arrived at from at least four years' experience of incandescent lighting.

The PRESIDENT asked whether interest on capital was included in the cost of the electric lighting.

Mr. SHOOLBRED understood from Messrs. Tate that interest on capital had been taken into account; but he could not say what it amounted to, as he had not all the figures. At both their establishments steam was supplied from a common source for driving the electrical apparatus and the rest of the machinery in the works.

The PRESIDENT said it appeared that the steam came from the main boilers, but there was no statement of what it cost.

Mr. SHOOLBRED said that, though the boilers were the same, there were special engines for driving the electric generators.

Great progress would be made in electric lighting by the introduction of central stations. Hitherto it had been customary to speak of steam engines of 20 or 30 horse-power as representing a considerable installation, but these were now being increased to engines of 100 and 200 HP. or more; and probably the plan that would be adopted in many cases would be that of direct driving, instead of using belts, which for such higher powers would not only be cumbrous and costly, but would entail considerable loss of motive power. Although a fair comparison of electricity and gas was at present rendered difficult by the smallness of the installations with which the paper had been dealing, all would agree in thanking

(Mr. James N. Shoolbred.)
the author for the care and diligence he had exercised in gathering together so many facts from so many branches of electricity. Probably those only who had closely followed the various applications of electricity could thoroughly appreciate the amount of labour involved in bringing together so much information of so practical a kind.

Mr. Magnus Volk believed electricity had occasionally been looked upon as though it were some formidable rival of mechanical engineering, whereas it was simply a means of transmitting power from place to place. The manufacture of a dynamo and a motor was purely a mechanical undertaking. The result from the dynamo was electrical, but afterwards by means of the motor the power was converted back again into mechanical force.

With regard to electric locomotion, he considered that on an electric line, instead of running heavy trains which required heavy viaducts and heavy permanent way—although perhaps the heavier the permanent way the better—the carriages should each be run separately, with an interval between; the power of the stationary engine could then be divided into motors as small as 1 HP., each taking one car for ten or twelve persons. The service of the line would then consist of a succession of cars, circulating along one line and back by the other; and as they would not all take the gradients at one and the same time, steeper gradients could be allowed, and the cuttings could consequently be lighter. With the motors as now made, the cars in running down hill gave a certain amount of power back to the motor, and thus an electrical balance was practically maintained between all the cars on the line. With respect to the depreciation of belts and the lubrication of driving shafts in factories, he might mention that the motors on the cars on his own electric railway, which ran along the sea beach at Brighton just above high-water mark, were hung on little stirrup-irons, and were only three or four inches clear of the roadway; there was no box or protection round them, and the salt air and dirt and dust floating under the car had free access to them. Those motors had now run for nearly four years, since April 1884; and they had only once had now solid

bushes, which had been put in last summer, so that they had run more than three years with only one set of bushes. Where a motor was put in a box made fairly dust-tight, as could be done in a factory, taking care that the wire should not be over-heated with the current, the wear and tear could be brought down so low that certainly 10 per cent. would amply cover all depreciation and renewals and repairs. The working expenses as given in the paper (page 94) for his Brighton line had been obtained from the result of two years' working. Having that morning gone through the books again himself, and having added up all the money that he had spent during the four years from the starting of the line, he had found that it amounted to £470 13*s.* 7*d.* for gas, oil, and cotton waste for the gas engine driving the dynamos, namely gas £437 18*s.* 11*d.*, oil £29 8*s.* 2*d.*, and cotton waste £3 6*s.* 6*d.*; repairs and re-facing the slides of the gas engine, and a little asbestos packing, came to £16 17*s.* 5*d.*; and repairs for two dynamos and two motors cost £64 5*s.* 6*d.* This last amount included re-winding an armature which had given way on a bank holiday when the car was so heavily laden that it could not start, and the fair amount would otherwise have been only £32; the items of which it was made up were—commutators £25 13*s.* 6*d.*, repairing armatures £29 4*s.* 0*d.*, brushes £4 8*s.* 0*d.*, and bushes £5 0*s.* 0*d.* After paying 10 per cent. per annum to the reserve, the average net interest earned during the four years had been 13½ per cent. per annum on the capital outlay, all repairs being paid out of revenue. Besides the above expenditure, £509 had been spent in repairing damage from the sea, all of which was included in the working expenses, thus leaving still a clear 10 per cent. reserve and 13½ per cent. interest. The mileage of the cars was 94,000 for the four years, reckoning the mileage of only one car, although he had run two in the summer. The result per car-mile was accordingly:—gas, oil, and cotton waste, 1·2*d.*; repairs to gas engine, 0·04*d.*; repairs to dynamos and motors, 0·16*d.*; wages, 0·7*d.*; total, 2·1 pence per car-mile. That was the actual result of four years' working. The number of passengers per mile run was 8·51; and the gross expenses, all of which were paid out of revenue, amounted to 55 per cent. of the receipts. On his

(Mr. Magnus Volk.)
small line therefore he thought he had thoroughly worked out the subject of electricity for light railways, using the ordinary rails as conductors; and he should be very glad if other engineers would now take up the matter of accumulator cars.

The length of his line at Brighton was rather under a mile; there were some very steep gradients on it, and he had originally prepared some differential clutch gear for climbing them. A gradient of 1 in 25 however he had found was ascended by the cars without any gear at all; so that he had simply taken off again the climbing gear which he had put on. On starting the line he had used a plain single leather 4-inch belt to drive the car wheels from the motor, but it gave way; and on two or three occasions the car stopped on the journey in consequence, and had to be pushed along by hand. Having at that time a prejudice against link belting, he had then tried a double leather belt; but as this had to go round so small a pulley at so high a velocity, the two plies came asunder, and it lasted only two days. He then tried the link belting, which he put on at the end of 1884; the same belting was running now, and he believed it would still last through next summer, if all went well. From three to four years might therefore be reckoned to be about the limit of duration for the link belting under the conditions under which he was using it. It had no protection from the wet or spray driving under the car. There was a 3-inch link belt for the first motion, and a 4-inch link belt for the second.

For joining the rails or conductors he believed the best method would be to use a flexible iron connecting-strap, riveted to the rails and then welded together electrically, as had been done by Messrs. Siemens on the electric railway along Ryde pier, thereby making one continuous piece of metal from end to end. On his own railway at Brighton he had drilled a ¼-inch hole with a twist drill through the end of the rail, and corresponding holes in line with it through the two fish-plates; and a rivet was driven in the rail and a separate rivet in each of the fish-plates independently, so that the joint could be undone as readily as if there were no rivets, the three rivets merely abutting against one another by their heads. In practice he found that, as they rubbed against one another under the passing

loads and the expansion and contraction, they kept constantly a bright surface if the joint was bolted up fairly tight. One of the rivets which had been driven out after having been three years exposed to the salt air was perfectly bright on the head, and the hole was as bright as when it was drilled, without the least oxidation in it. The railway was on the sea beach at Brighton, between the centre of the town and the east part, running alongside the highway: it was properly a light railway of 2 feet 9 inches gauge, and there was a succession of cars running backwards and forwards. Where such a plan might be adopted on a more extensive scale, he did not mean that the cars were to run without conductors or drivers, but that reasonable care should be taken to keep them at proper distances apart. He had found no difficulty in working the cars in parallel, and each seemed to take its fair share of the current; there were only three cars working at any one time, and so long as there was sufficient current there seemed to be no difficulty about working them in parallel.

The PRESIDENT asked whether there would not be some danger of separate cars running into one another when going up and down the different inclines.

Mr. VOLK presumed the drivers would take care to control the speed, so as to keep the cars a proper distance apart.

Mr. M. HOLROYD SMITH thought that, in surveying the large and wide field of engineering embraced in the paper, it was no small credit to the author to have arrived at conclusions so sound on the topics with which he had dealt. In the representation made in page 76, that the science of electricity was much behind in America, he took exception to the word "much." At the same time, while remembering such names as those of Thompson, Preece, Hughes, Hopkinson, Kapp, and many more in this country, it must not be forgotten that on the other side of the Atlantic there were such men as Franklin, Edison, Elihu Thomson, Brush, Houston, and others, who had done very valuable work from which Englishmen had

(Mr. M. Holroyd Smith.)
profited. Perhaps the fact that practice in this country was behind that in America was not altogether due to laws and monopolies; even high scientific attainments themselves might sometimes prove more or less a hindrance to practice, by suggesting so many ways of doing a thing that it was not done at all. In America as soon as a way was found out the thing was done at once, and was continued to be so done until some better way was discovered; and this he thought lay at the bottom of the greater advance which was now being made in America in comparison with the progress in England. Moreover the British public were hard to please, while the American public were easily satisfied. On first arriving in New York he had wondered how it was that such an eye-sore and nuisance as the overhead railway in that city could be tolerated; but he had not been there more than a fortnight before he found that the convenience and comfort of the overhead railway far out-balanced the nuisance. The same he thought would be the experience in regard to a great many things in this country, if certain insular prejudices could only be set aside. In regard to the science of the American electrical engineers, it was only necessary to look at the drawing of the Brush machine in Plate 23 to see that they were not so very far behind this country. In connection with transformers he had been shown in New York an instrument which he was assured was capable of transforming continuous electric currents of a high potential into continuous electric currents of a low potential, and *vice versâ*. Not having seen the inside of the instrument, he had no idea how the object was accomplished, as no motors or batteries or dynamos were used.

Another matter for which he thought the Americans deserved considerable credit was electric welding. Two methods had been mentioned in the paper, that of Professor Elihu Thomson and that of Dr. Bernardos. The conclusions at which he had himself arrived, from his own experience in the very difficult process of welding fine wires together before they were drawn through the block, were confirmed by the experience of all mechanical engineers in regard to welding generally; and he was satisfied that the plan

employed by Dr. Bernardos of using the intense local heat incident to an electric arc was quite out of the question for producing a sound and solid weld; it was simply fusing the surfaces of plates together, and was not welding at all. The attempt to weld wire together by means of an electric arc would certainly be an absolute failure. On the other hand the method introduced by Professor Elihu Thomson in his works at Lynn, near Boston, Massachusetts, which he had had the pleasure of visiting, was one that contained elements of success; and he had brought with him for exhibition some samples of welding which he had himself seen done there. One was a fine wire of copper, which he saw welded by electricity; and any one who liked to try would find he was unable to break the wire at the weld. Another was a bar of copper, which he saw welded in the same way; and the third was a bar of iron similarly welded. A large current of electricity was brought to two vices or clips that held the two pieces of iron or copper to be welded. The ends of the two pieces just touched each other, the current was turned on, and as the ends of the pieces got gradually warm and then hot up to the point of fusion they were pressed together and so welded. It was quite under the control of the operator how hot the metal should be made, and what the force should be to press the pieces together; they were gradually squeezed and squeezed closer till the metal formed a burr all round the weld, which was thus made completely sound. The result was most satisfactory, as it would be seen from the specimens exhibited that the welding was perfectly sound.

With regard to the cost of haulage by electricity, he was much obliged to Mr. Volk for having given (page 121) so comprehensive a statement of the method on which he based his cost of haulage at Brighton. There was so wide a variation in the statements of the cost of haulage on different lines that it was clear there must be some difference in the basis by which the figures were arrived at; and it was therefore highly desirable that there should be some agreement as to what were to be considered the fair items to be charged in the cost of haulage.

(Mr. M. Holroyd Smith.)

Mention had been made in the paper (page 78) of motors that maintained a constant speed under varying loads; and he thought great praise was due to those who had succeeded in accomplishing this object. But it must be remembered that on tramways or railways there was not only a varying load to be dealt with, but also a varying speed; and a motor was wanted that would carry varying loads at varying speeds. The power required to start a train was very much greater than the power required to keep it in motion. If a line was well designed, he generally reckoned about 20 lbs. per ton for tramcar haulage, and about 60 or 70 lbs. per ton for starting, which was a very great difference. If a car were started up hill, the motor driving it had to do the heaviest work at the lowest speed. Tramways had often to be made with steep gradients: Mr. Volk had spoken of 1 in 25 on his Brighton line; but this was not so steep as the first gradient that he had himself had to overcome, namely 1 in 16; and in starting up such a gradient with a heavy load there were of course severe strains upon the dynamo. Hence in dealing with the question of self-governing, where there was not only a varying load with constant speed but a varying load with varying speed, a difficulty arose that was not very easily solved. This frequent and sudden variation of the load, so much greater than occurred in electric lighting, necessitated special care in designing and constructing the generators. A prominent example of what could be done was furnished by the dynamos supplying the current for the cars on the Bessbrook and Newry tramway; and their continued practical success was highly creditable to Dr. Hopkinson, by whom they had been designed. Yet although the makers of shunt and compound wound dynamos had every confidence in them, and for lighting purposes justly so, he was not disposed to depart from his present method of separately exciting the field magnets; the advantages resulting from so doing in his opinion more than repaid the extra outlay.

With regard to the mention made of worm gearing in connection with his electric tramway at Blackpool (page 90), none of the cars at Blackpool were worked with worm gearing; but he had used it

successfully upon his Paris cars. A suggestion had also been made as to how cars should be geared up; and it might be interesting if he described the way in which the Blackpool cars were geared, as shown in Fig. 20, Plate 24. The pinion M upon the end of the motor shaft geared into an internal toothed wheel W, upon the outside of which there was a chain pinion P, geared by a chain to the chain wheel C upon the axle of the car. For tightening the chain when it became slack, as it was very likely to become, the internal toothed wheel W was carried by a bracket or arm A centred on the motor shaft; so that, no matter at what angle the arm might be set for tightening the chain, the wheel W and pinion M were always properly in gear. This plan allowed of slackening the chain with the greatest facility for getting it on or off; and after putting it on, the arm was secured by locking bolts in the position that gave the requisite tightness. Another point was that in starting the chain gear the chain was of course quite slack, and practically there was no friction as in the case of belting. When driving with a belt there must be friction on the pulleys, and that acted more or less as a brake or dead load at starting: whereas in a chain when slack there was no friction beyond the mere weight of the links, which could be disregarded. As soon as the electric current turned the motor, there was nothing to resist the movement of the driving pinion until it was jerked up by the strain upon the chain; and he thought it was in this jerk that part of the difficulty had arisen in the chain gearing used on the Bessbrook line. In order to overcome it the chain wheels on his Blackpool cars were constructed with a loose annular rim, connected by spiral springs S to four arms which were keyed upon the axle of the car wheels. As soon as the motor started, it had first to brace up this connection by elongating the springs; and that took the jolt off the chain altogether. The duration of the chain on cars provided with these springs was much greater than before they were applied.

On the question of secondary batteries a conviction had recently been expressed by Mr. Preece * that secondary batteries would before

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* Journal of the Society of Arts, 20 January 1888, page 189.

(Mr. M. Holroyd Smith.)

long be satisfactorily used for tramcar haulage. While he should be glad if such an object could be accomplished, he had the gravest doubts about it, in consequence of the differences between secondary batteries and direct driving. There was first of all the additional weight on the car, practically doubling the load to be worked. Then on going into figures he found that the cost of an installation would be very much greater when secondary batteries had to be used than when direct driving was employed. Secondary batteries answered when there were only one or two cars to run over a long length of line; but it was otherwise with a whole system of tramcars where a frequent service was required, as in a recent case submitted to himself where there were 200 cars to be run upon 20 miles of line. If it were attempted to fit up 200 cars with three sets of batteries each, which was the least number prudence would require, the cost of the installation he thought would be nearly twice as great as he had estimated it to be with direct driving. Then there was a difficulty in getting a secondary battery that would work satisfactorily unless it was quiet. Secondary batteries were all right for stationary work, if care was taken that they were put in a cellar, in a cool place upon a strong foundation; but as soon as there was a slight jolt, they objected, and did not behave themselves as they ought. Secondary batteries he admitted were better than horses; but that was only going half way towards the substitution of electricity.

The working of three cars in parallel on the Brighton line had been mentioned by Mr. Volk. In Blackpool ten cars were frequently worked in parallel, and there was no difficulty in each car having a proper quantity of electricity when the driver so willed. As to the question of runaway cars, the motor could be so wound that it would not exceed a certain speed, no matter how careless the driver might be: he could not compel the car to go faster than the regulation speed of eight or nine miles an hour, as might have been previously determined. That was a very valuable element in a motor of any kind.

With reference to the production of aluminium, the enormous profusion in which that metal existed in the world was well known,

as well as the great difficulty hitherto experienced in reducing it from its ores. The expense of the existing method, whereby it was smelted with a flux of sodium, was due he believed to the cost of the sodium used for the purpose. A new process he understood had been discovered in America, whereby the cost of sodium would be reduced to one-tenth. If sodium could be obtained at so low a rate, it would render the existing method a formidable competitor with the new process of smelting by electricity. The commercial result required was pure aluminium; and so far electricity had succeeded in producing only an alloy.

Dr. John Hopkinson mentioned that in the early plans of overhead conductors either a hollow tube had been used, with a travelling piece running along inside it and connected with the car by means of a flexible connection; or else a wire had been used, with a little car running upon it, which was again connected with the tramcar by a flexible connection. In the plan which he had suggested, the conductor was hung precisely like a telegraph wire from insulators overhead, the insulators being kept at approximately the same level. On the tramcar, front and back, was arranged transversely a contact bar, so that the contact with the wire overhead could be made at any point in the width of the car. This arrangement had great conveniences, particularly for going round curves and passing junctions, because the position of the car might be varied laterally in relation to the conductor without any inconvenience or difficulty whatever. The only question was whether in this way a thoroughly good contact could be ensured between the contact bar on the car and the conductor overhead. If the plan had been proposed in time, it would have been adopted on the Bessbrook tramway which had been designed by his brother; but the third-rail conductor had already been delivered before this plan was devised, and consequently the overhead conductor was used only for the purpose of getting over a level crossing, where the conductor between the rails was absolutely impracticable. This application however had been quite sufficient to test the practicability of the method. It was a single span of fifty yards, where the

(Dr. John Hopkinson.)

overhead conductor had now been in use for about two years without any apparent sign of wear and tear; so that he thought it had given the practical proof which was requisite.

In regard to the self-regulating property which a shunt-wound Victoria motor possessed (page 78), a shunt-wound dynamo with a constant potential would run at approximately constant speed; that was not a peculiarity of the Victoria dynamo, but was a property possessed also by many others. It was however a matter of some interest to point out the reason why there was a more perfect self-regulation with a shunt-wound motor than with a shunt-wound generating machine. If it were only a question of the resistance of the armature, the two cases would be exactly alike; but that was not so. In a generator of electricity, when the current passed in the armature it was necessary to advance the position of the brushes so as to give them a lead, and then the current in the armature had the effect of diminishing the magnetic field; and this had to be compensated by what was known as compound winding. In order to obtain constant speed it would be necessary to diminish the magnetic field. In the case of a motor, it was necessary for the brushes to have not a positive lead, but a negative lead; they had to be set back, and the current had also to be in the reverse direction. Hence by the action of the current in the armature itself a reduction of the magnetic field was obtained, and thereby precisely the same effect was produced as would result from inverse compound winding. If it so happened that this effect was precisely the amount required, perfect self-regulation would be obtained in the shunt-wound dynamo. In most cases the effect would be either a little in excess or a little in defect; but theoretically speaking it was practicable with a dynamo motor to obtain perfect self-regulation without any compound winding at all.

Sir James N. Douglass, Member of Council, said his own experience upon the subject had been only in one branch—that of electric lighting. Reference had been made to the slow progress effected in this country in the development of electric engineering; but he thought that, if it had not gone on very rapidly, it had yet

not gone on very slowly. The lead had been taken in England, and it had been fairly followed up, although perhaps commercial undertakings had not progressed as much as might be desired. It should however be remembered that installations which were considered to be perfect at the time they were established had within a short period fallen behind and been superseded altogether in the wonderful development that had been going on. In the service with which he was connected, commencing in their own way very perfectly as they thought at the time, they had afterwards found that their early dynamos had become obsolete. That was sufficient to deter a country like England from making very rapid progress in installations for general electric lighting. He well remembered that, when Faraday saw the first dynamo of Holmes in 1856 at the Trinity wharf at Blackwall, he said "This was my child, but you have made a man of it;" and had he been living he would now admit that the man had become a very great giant. His own work lay in the development of electric lighting for the service of the mariner; and up to the present time it had been applied only at important sites where oil and gas would not meet the requirements that were demanded. Electricity furnished a power which appeared actually to go beyond what was required. In the best installations, of which one of the most important had been due in a great measure to the labours of Dr. Hopkinson, it met every possible requirement of the mariner, whose sole complaint was that he sometimes had too much light. Without attempting to criticise the paper, he would only express his own satisfaction at the complete way in which the subject had been brought forwards by the author.

Mr. R. E. B. CROMPTON, referring to the remark on the first page of the paper, thought it could hardly be admitted that the practice on this side of the Atlantic was behind that in America. All the great practical improvements in the dynamo machine, which was the most important of all electrical engines, had been made he considered in England. The machines designed and perfected by Dr. Hopkinson were probably ahead of any others in the world. The machines made by Messrs. Siemens in London were

(Mr. R. E. B. Crompton.)
certainly far ahead of those made in Germany by the same firm; and both these machines, to say nothing of others of English design and manufacture, were far ahead of anything that had ever been made in America. Referring to the large Brush dynamo represented in Plate 23, he thought there was not a mechanical engineer who would not smile at the idea of putting 400 HP. through a spindle of the size there shown. It so happened however that, though designed to develop 400 HP., it really developed in actual work only 200 HP.; whereas it had fallen upon himself to have to design the largest dynamo in the world, for developing 500 HP., and the dynamo could actually develop this power. The bearings in his own machine however were 30 inches long, instead of only something like 20 inches which appeared to be about the length of those shown in Plate 23. It was apparent therefore that there were different ideas as to the amount of surface required to take up the pull of the heavy belts necessary for transmitting 400 or 500 HP. This was simply a matter of practice, and not a question of pure science; and in such matters he considered that English engineers were not behind the Americans.

As to the chances of cheapening the production of aluminium through the recent improvements which had resulted in cheapening sodium (page 129), he thought most chemists would agree that an element so difficult to dissociate from oxygen as sodium was not likely ever to be dissociated except at great expense of fuel; and if fuel were used at all, it would be better to use it for driving the dynamo in the Cowles process than for producing the high temperature required to dissociate sodium from oxygen. He therefore did not believe in any kind of sodium process producing aluminium at less than double or treble the cost at which it could be done by the electric furnace. Though he had only once worked the electric furnace personally, he had found it the easiest process to manipulate that he had ever carried out. On that occasion he had supplied the requisite electric apparatus to some works in Austria; and when the furnace was started to work it seemed difficult to believe that the heat inside was anything more than that of an ordinary blacksmith's forge, and yet all the while the furnace

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was working at the intense heat required for reducing a large ingot of aluminium bronze, containing about 50 per cent. of aluminium, direct from the corundum. Until turning out the contents of the furnace on the completion of the operation, he had not at all realised what had been going on; it seemed perfectly extraordinary that such intense metallurgical action should go on in such a confined space, with so little communication of heat externally.

The probability of accumulators being worked on tramcars he thought had been materially enhanced by the fact that there were several electric locomotives running with great success on the North Metropolitan Tramway according to the Elieson system mentioned in page 94 of the paper. This line had been running continuously for months past, and had carried more passengers he believed than any other electric tramway constructed in England.

Mechanical engineers hardly knew the enormous future there was for this new industry of electric engineering; they hardly yet appreciated that it had got out of the region of small telegraphic instruments. Some indeed had already seen in their visit to his works in 1886 (Proceedings 1886 page 413) the masses of metal and the kind of machinery he used for turning out modern electrical appliances; the class of machinery employed for making modern magnets was more like that for turning out armour-plates. The promise of the electrical machinery of the future was that it would constitute a very important addition to the production of mechanical engineering works throughout the country, and would carry with it a large development of trade.

Mr. CHARLES COCHRANE, Vice-President, mentioned that his firm at Middlesbrough had recently been induced by electricians to try at their Ormesby Iron Works the Parsons steam turbine, which he thought showed some progress beyond all that had been described up to the present time, seeing that it was self-contained, and belts and gear were entirely dispensed with. It was capable of running regularly at 10,000 revolutions a minute, the whole being balanced by the beautiful arrangement of the turbines, right and left; the steam was supplied into the centre of the

(Mr. Charles Cochrane.)
apparatus at one end at 50 or 53 lbs. pressure, and came out at the other end he was told at something like 2 or 3 lbs. pressure in the exhaust. That engine had been at work only a few weeks, and he was therefore unable at present to give further information about it; but with its admirable bearings floating in oil—a chief feature in the arrangements being the securing of a constant supply of oil to the bearings—it was one of the most beautiful contrivances it had ever been his lot to see. It had been supplied to his firm by Messrs. Clarke Chapman and Parsons of Gateshead.

Mr. Thomas P. Gower said the cars carrying storage batteries, on the plan which was mentioned in page 94 of the paper as being tried by Mr. Elieson upon the North Metropolitan Tramway at Stratford, had now been running there for six months, doing continuous heavy work, covering about 30,000 car-miles, and carrying about 300,000 passengers or more. Mr. Crompton therefore was probably right in believing (page 133) that during that time the batteries had done heavier work than had been done on any other electrical tramway in the kingdom. There was certainly considerable cost at present with regard to the accumulators; but he thought electrical engineers would be very wrong if because of present heavy cost they dismissed accumulators as a means of future effective traction. For engines worked by storage batteries were capable of running on any properly laid line, from any shed where the accumulators could be charged from a dynamo driven by a steam engine or a gas engine; whereas with any system of conductor the prejudices and objections of local and other authorities had to be encountered. There was the greatest possible difficulty in getting any plan adopted of overhead or underground conductor, except in tunnels and such places where the engineer had the practical control of the line. Having been somewhat forcibly impressed with the apparent vagaries of accumulators, he had nevertheless come to the conclusion that it was very largely a mechanical matter to manage them well. In his own experience he had found that very great advantages were to be gained from a better method of packing the plates. Originally they had been screwed together immovably, and between the places

at which the plates were bound together the surfaces were very small: consequently, when any swelling took place in the plates, buckling was inevitable. He had therefore altered the mode of packing, so as to let the plates be as free as possible while still attached to the lugs. Since that time the principal makers of accumulators had gone in precisely the same direction, leaving the plates in a very free condition, so that there should be scarcely any tendency to buckle, and the swelling should be in a direction which would do comparatively little harm. Another matter of importance in the use of accumulators was that they should be very readily got at and very frequently overhauled. If these practical points, and others which would arise in connection with accumulators, were properly attended to, he believed it would be found that accumulators were much more manageable, and could be used with much less cost and depreciation, than had been imagined up to the present time.

Mr. GISBERT KAPP confirmed the statement given in the paper (page 87) as to the efficiency of the electric transmission at Solothurn, in regard to which Mr. Snell's remarks (page 112) appeared to be made under some misconception. The first experiments with the machinery had been made whilst it was still in the maker's shop, where the conditions of actual work could only be imitated in a more or less imperfect way by substituting artificial resistance for the resistance of the line; moreover it was not possible to foretell what might be the leakage of electricity along the line, which of course would lower the efficiency; nor could the motor be loaded so regularly. The designer of the plant was an Englishman; and the makers, thinking it advisable to have a correct set of tests made, asked six mechanical engineers of high standing in Switzerland to go and test it, one of them being Mr. Amsler, the inventor of the planimeter. From their report it appeared that the efficiency was actually 75 per cent., the power given out by the motor at five miles distance being 75 per cent. of that developed by the turbine in driving the generator. Thus the author's statement of 70 per cent., which was made before these tests had been carried out, was well on the safe side. As to the absolute power being smaller than that stated by the author, he

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might add that since the paper was written a 100-H.P. transmission had been started at Lucerne by the same designer.

The apparatus mentioned by Mr. Holroyd Smith (page 124), for converting a continuous high-tension current into a continuous low-tension current, appeared to be somewhat similar to one which he had himself tested at the Newcastle Exhibition last year, when he found the efficiency to be something like 90 per cent. Since then he had found that six or eight years ago Mr. Gramme in Paris had done exactly the same thing, but conversely, transforming the low tension into high tension for the purpose of telegraphing over a long distance where the line had great resistance, and where in the ordinary way of telegraphing a large number of cells and batteries would be required to force the current along the line. Having at hand a small number of fairly large cells, which gave a large current but not enough electromotive force for telegraphing to the desired distance, Mr. Gramme constructed one of his ordinary magneto-motors, but with two circuits in its armature, one of fine wire and one of coarse wire. There were two commutators, corresponding with the windings of fine and coarse wire, and the primary low-tension battery was connected with the brushes of the coarse-wire commutator. That made the armature revolve, and through the revolution of the armature a high-tension current was induced through the fine wire, which was used to telegraph along the line. This apparatus had now been advocated for use in lighting towns where the district was extensive; a small wire could be employed for carrying electricity from the generating station to the point of consumption, where a rotary transformer would convert this high-tension current into one of low tension, which would be distributed by mains and house connections for supplying lamps or any other appliances to be worked by electricity. In this manner the high-tension current could be transformed into a low-tension current, and distributed in the same way as if it were generated on the spot.

Switches and crossings in the overhead conductor on an electric tramway were clearly a very great difficulty. For whether the conductor were a hollow tube with a shuttle travelling inside it,

or a wire along which ran a small car, it was very difficult at the switches to make the shuttle or car follow the particular connection desired, right or left; and consequently the use of an overhead conductor was practically limited to cases where there was a single line without branches coming off it. In Scranton, Pennsylvania, where one of the earliest electric lines was worked with an overhead conductor, a branch had subsequently to be put in, and great trouble had been experienced with the switches. Since then Dr. Hopkinson had invented his ingenious plan, in which there was no need to alter any of the permanent arrangements overhead, because wherever the car happened to be it took up the current. The same idea had now been carried out in a new plan of underground conductor, which was the invention of Mr. Lineff, and had been laid down on a small experimental line of the West Metropolitan Tramway at Chiswick. Described briefly it was Mr. Holroyd Smith's underground conductor, modified in the way in which the overhead conductor had been modified by Dr. Hopkinson. As shown in Figs. 21 and 22, Plate 24, there was the same underground conduit laid centrally between the tramway rails, as in Mr. Smith's plan, with a slot all along the top for the connection from the conductor in the conduit to the tramcar on the road. But instead of the conductor being left bare along its entire length for the carrier to rub along it all the way, which was a disadvantage because it collected moisture and gave so much facility for surface leakage, the conductor was here insulated for nearly the whole of its length. The conductor consisted of a copper wire, which was simply laid inside a $\frac{3}{4}$-inch gas pipe G; the pipe was covered over with some insulating compound, and was carried on brackets fixed inside the underground conduit. At every three feet there was a T piece on the pipe, and into the T piece was screwed an inverted cast-iron saddle S, which was connected with the conductor so as to form a contact piece, and was not insulated. From each end of the tramcar a bar B projected downwards through the slot, and between the bars was suspended an ordinary steel cable C, the bight of which hung inside the conduit and was long enough to lie always in not less than two of the saddles S at the same time. To facilitate the free entry and exit of the cable, the groove in the

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saddle was made with an easy opening transversely, and the ends of the saddle were curved downwards; and in order to protect the cable itself from getting frayed by rubbing over the saddles at a speed of six or seven miles an hour, a number of gunmetal ferrules were strung loosely upon it, which were free to revolve, and when worn out could be replaced without having to throw away the cable itself. The advantage of this plan was that it allowed of crossings on the line at any angle, owing to the intervals between the successive contact saddles; the great difficulty that would arise at a crossing in maintaining a continuous contact all along the surface of the conductor was thus obviated.

Mr. M. Holroyd Smith said the transformer described by Mr. Kapp was well known to himself, and was distinct from the instrument he had seen in America, in which there was no motor, no frame, and no revolving piece that had to be kept in motion. How it was to be done he failed to see; but he hoped it had been done.

Mr. Henry Davey, referring to the use of electricity for the purpose of working pumps in mines, as advocated in the paper, fully believed that electricity as a distributor of power would have a very wide application; but care must be taken not to apply it under incompatible conditions, otherwise it would only be brought into disrepute, as he thought would certainly be the case in applying it to the above purpose. In considering the mechanical details and arrangements for pumping water from mines by means of electricity, he failed to see in the first place how electricity could possibly be applied to drain mines that had large quantities of water, such as were usually drained by means of surface or underground pumping engines. The application contemplated in the paper he imagined was that of draining the dip or remote portions of mines by means of small portable pumps; and even there he thought such an application would be decidedly a mistaken one. In Fig. 4, Plate 18, was illustrated the application of electricity to such a pump, commonly known in collieries as a dip pump. The usual method of working such pumps was to lead off at the bottom of the shaft a little pipe

from the rising main of the main pumping engine to a small direct-acting hydraulic engine for working the dip pump. Nothing could be simpler or more effective than that plan, the efficiency of which must be much higher than of any electric arrangement that could possibly be devised. Besides this, these dip pumps very often became drowned, and had to work under water. What would become of the electric motor in such a case? Then again, as the motor usually ran, according to Mr. Walker (page 113), at from 800 to 1000 revolutions per minute, while the pump should not be driven faster than 30 or 40, it was necessary to put in complicated gear for reducing the speed, which must entail a great loss of efficiency: so that he was convinced any such application of electricity must in the end prove a practical failure. Where however electricity would advantageously come more extensively into use would be where power had to be transmitted over a very considerable distance; and there it certainly did appear to possess in point of efficiency very decided advantages indeed, even judging from the limited experience which had already been acquired. It thus afforded a ready means of utilising water power in districts which possessed that water power, but which were remote from centres of industry. For that extensive application he thought transmission of power by electricity would come in better than for any such limited application as the working of underground pumps in mines, which was at present done by other machinery in a very satisfactory and practical manner.

Mr. William M. Mordey believed that the failure of a portion of the electric lighting at the Colonial and Indian Exhibition in 1886 (page 109) had been due not to any leakage of the wires, but rather to an unfortunate error of judgment in using a kind of machine for arc lighting with constant current which was not suitable for that class of work. About 190 lamps out of a total of 400 had been worked by the Brush Corporation under exactly the same conditions as were prescribed for the other contractors, the cable being supplied by the Exhibition authorities, under whose supervision it was put up. As far as the Brush circuits were concerned, there had been

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hardly any interruption of the light from any cause. A fine of a penny was imposed for every minute that a lamp did not burn or even burned badly; and the total fines for the whole of the 190 lamps during the entire period of the lighting amounted to only 35*s.* 8*d.* Thus out of 6,840,000 lamp-minutes one lamp was burning badly, or was out, for 428 minutes; this showed that it was quite possible to employ arc lighting with an exceedingly small proportion of failures. At last year's Manchester Exhibition about 550 arc lights were carried out by the Brush Corporation on the same principle, and he thought there were hardly 20 extinctions during the whole time. There could be no doubt whatever that electric-lighting plant was at the present time, as it had been for some years, quite beyond the experimental stage. The fact mentioned in the paper (page 101) that in one case a Victoria dynamo had been running for a couple of years, day and night except Sundays, showed that there could be no doubt as to the machinery being trustworthy.

In connection with the curve of speed regulation shown in Fig. 1, Plate 17, it had been correctly remarked by Dr. Hopkinson (page 130) that the Victoria motor was not singular in being able to give a very constant speed with varying loads when supplied from constant-pressure mains. At the time of that curve being published by himself in the Philosophical Magazine in January 1886, the fact was not known, or at any rate not then recognised, that simple shunt-wound motors were capable of being made perfectly self-regulating. Only a few weeks before that publication, a long investigation into the question of the self-regulation of motors had been published in Germany by Dr. Fröhlich, who, although he had tried shunt, compound, series, and differential motors, had entirely missed the point which was necessary for obtaining constant speed-regulation in shunt motors. He had therefore published the curve drawn in Fig. 1, simply to show that such motors would give constant speed, and to point out that the right way to construct a motor was pretty much in the same way as a dynamo, namely to make a strong field and weak armature magnetically. Up to that time it had been generally considered, following the theories of Professors Ayrton and Perry,

that the right principle was to have a very small weak field and a large strong armature.

As to the relative positions of English and American electrical science and applications, he thought American practice was ahead in the sense that as soon as Americans got hold of anything that would work they applied it at once. Most of the real advances in regard to dynamos had originated on this side of the Atlantic; but in America electricity had been applied for lighting purposes and for power transmission to a vastly greater extent than on this side of the Atlantic, and particularly in this country. Englishmen seemed to make the improvements, for the Americans to make money out of their application. Since the publication of his curve, shown in Fig. 1, Plate 17, there had been made and used by one company in America over 5,000 motors, while all the English motors put together since that time would not amount he believed to much more than 50. Mechanical engineers were perhaps a little to blame for this, through not realising yet the capability of electricity for the transmission of power; they did not yet know what a tool electricity gave them. The present paper therefore he hoped would do something at any rate to open the eyes of those who would ultimately be most concerned in its applications, but who so far seemed to be unaware or sceptical of the great capabilities of electricity, quite apart from lighting.

As to the large Brush dynamo shown in Plate 23, which was alleged (page 132) to have given only half the power it was supposed to give, he had some time ago looked up an official test, from which he thought there could not be any question as to the machine giving the full power intended, and so far as he knew the machine when tested had given rather more than it was designed for. A good proof of this was that the Cowles Company in America he understood had ordered two or three more machines of the same kind and size, and also one larger.

The PRESIDENT observed that the cost of electric lighting had been given by Mr. Fearfield as 2*s.* 1*d.* in comparison with 2*s.* 4*d.* by gas; whilst from the statement in page 101 of the paper the cost of

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electric lighting would appear to be considerably less than two-thirds of that by gas. Coal was there taken at 3 lbs. per HP. per hour for the electric lighting; and he should be glad to know whether that was the result of actual measurement, or whether it was merely estimated from a series of boilers employed for supplying steam to the rest of the works also. Had the condensation in the steam pipes been taken into consideration, and leakages and other extras, such as getting up steam at the beginning of the week? Then there was the item of repairs, including men's time attending dynamo; was there anything included in that for the repair of the engines and boilers? Then came depreciation at 10 per cent.; did that cover the cost of depreciation of engines and boilers? Of course if all these different items were left out of the calculation, it might be shown that electric lighting was very much cheaper than anything else; but what he wanted to know was, what would any company undertake to supply electric lighting for, so as to include everything, for that was the main question in considering the cost of lighting by electricity as compared with gas. The subject must be looked at from the point of view of what the cost would be; and he should therefore like to know whether the figures given in the paper were only estimated or were the result of real measurement.

Mr. Geipel thought Mr. Fearfield's experience must have been particularly unfortunate (page 108) in regard to engine-drivers who were not able to look after dynamos well enough to prevent the armature from scrubbing, the commutators from wearing, and the brushes from sparking. Having himself had a good many installations under his control from time to time, he had in very few cases been able to get engineers to look after dynamos, and had had to be satisfied with men who oiled the shafting, or with other unskilled attendants, such as sugar boilers, as at Messrs. Jager's sugar refinery, referred to in page 101 of the paper; the sugar boilers there looked after the dynamo, and did all that was required to it. If anything did happen to go wrong with this dynamo—though, as mentioned in the paper, nothing of the sort had occurred for two years—it would of course be necessary to call in an engineer; but

as far as concerned oiling the bearings, adjusting the brushes, and keeping the dynamo clean, he did not consider it should be requisite to employ an engineer at all. The same remark applied also to motors equally well; there was no reason why a workman should not be able to oil his own motor at his own machine, and to keep it running satisfactorily.

The mention of a 4-inch belt in page 80 was merely taken from a letter he had received from America, and referred only to a portion of the work that the motor was doing; and it seemed to him that the meaning of the expression "a 4-inch belt" was quite as intelligible as "a 10-HP. engine," because of course the amount of work a belt was capable of doing depended upon the speed, precisely as the amount of work an engine did was dependent upon its speed.

A comparison had also been made (page 110) between steam pressure and electrical tension or potential: it was said there was no reason why electricity should not be worked up to 10,000 volts, just as steam was at present worked at 160 lbs. The comparison did not quite hold good, inasmuch as steam would scald at any pressure, whereas electricity would not injure at all at low tension, but would kill at higher tension. Moreover as the steam was confined within the boiler, it was only through the medium of the boiler that it could inflict injury upon the human body, whereas electricity affected the body directly; engineers had effected improvements in the strength or resistance of the boiler, which they were not capable of effecting in the human body. On the other hand it might fairly be argued that, inasmuch as currents were now in daily use of 2,000 volts tension, which was already more than the human body could stand, there was no reason why 10,000 volts should not be used in the same way; and the higher tension would of course be attended with the advantage of a saving in the loss of power and in the transmission of current.

As to how far the size of the installation controlled the working cost (page 111), in his own experience the size of the installation had very much less to do with the cost of working than had the length of time during which the installation was used per annum, or the amount of use that could be got out of it. Of course it would not

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do to push that view too far, and to say that if one lamp was worked long enough it could be worked as cheaply as a hundred; but taking a reasonable installation of a thousand lamps or more, the cost of working was very much more dependent on the time during which the lamps were alight than upon their number. The curve drawn in Fig. 2, Plate 17, showed how much the time during which the lamps were alight per annum affected the cost of the light per lamp-hour: for the higher numbers of hours the cost seemed to become fairly constant; but as the duration fell off towards 100 hours per annum, the cost rose very rapidly.

In regard to the estimate (page 77) of 10 to 5 per cent. for the loss of power in the conductors, which was considered by Mr. Walker (page 112) to be too much to lose, that depended very much upon the cost of the power it was intended to transmit, upon the cost of the conductors and of their insulation, and also greatly upon the time during which the current was used. In Table 5, page 102, was shown how much potential it was economical to lose for different cases. It did not follow that in all cases 10 to 5 per cent. might be lost; but he thought this was a reasonable percentage to lose, more especially in this country where coal was so cheap.

In reply to Mr. Walker's enquiry (page 112) as to how a 6-HP. electro-motor could compete with a 10-HP. steam-engine, the 10 HP. mentioned in page 80 he supposed was merely a nominal term; and moreover the driving power of a steam engine did not increase with the load upon it. If the speed of an electro-motor were reduced by putting on an increased load, its rotating or twisting moment or "torque" was thereby increased. This did not mean an increase in the amount of horse-power developed, but an increase in the amount of machinery that the motor was able to drive at the lower speed. For instance, by throwing on an extra printing machine in a printing establishment, it was possible that the engine might be almost or entirely stopped, in consequence of being able to exert only a certain power on the driving shaft, irrespective of the speed; whereas with a motor, if it were pulled up to a slower speed by an increase of load, a larger current passed through it and its moment or torque was thereby increased at the slower speed.

In regard to obtaining electric lamps of 200 volts (page 116), he had not yet been fortunate enough to meet with any of so high a resistance, although he understood that Mr. Swan, who had had so much experience in manufacturing electric lamps, saw no difficulty and no reason why they should not be made by improved manufacture. The curves of voltage in Fig. 3, Plate 17, were drawn not so much in reference to the potential of the lamps as to that of the current employed to light them. The lighting might also be done on what was known as the three-wire system, according to which the power could be distributed by currents of 200 volts, while yet lamps could be used of only 100 volts. In America he understood the Edison Co. were using lamps having in some cases a resistance as high as 150 volts. In mentioning transformers (page 104), and also in page 78, he had drawn particular attention to the importance of being able to work motors from the street mains.

The question asked by Mr. Barcroft (page 112) as to the method of joining the rails on the electric railways in America had already been partly answered by Mr. Volk (page 122); and there should be no difficulty in joining the rails by various methods. He had known electric railways work quite satisfactorily with merely fish-plates alone, without any other connection, provided the rails did not carry both the going and the returning current, but were used for the returning current only. The Victoria motor referred to in page 78 would not run away if short-circuited.

As to American engineers having taken advantage of what European men of science had discovered, he considered that Prof. Houston or Brush or the other Americans who had been mentioned, with the exception of Franklin, were not so much men of science as really practical engineers who had taken the best advantage of the discoveries made by Faraday, Gramme, and other Europeans. While Great Britain did not represent the aggregate of European science, neither did he wish to depreciate the immense amount of good work done by the Americans.

The sample exhibited of electric welding from the works of Dr. Bernardos he agreed was bad; but he thought it would be premature to condemn that method altogether, until further trials

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had been made. Better results he considered might be obtained by increasing the size of the arc, or by using more arcs than one, so as to render the heating less local.

The suggestion (page 125) of a general basis for calculating the cost of working tramways he thought was hardly likely to be accepted, because the conditions of working railways and tramways were too numerous and diverse; but it was not a difficult matter to arrive at the working cost of any railway in operation, whether electric or steam.

It was not stated in the paper that self-regulation was peculiar to a Victoria motor; on the contrary, the statement made in page 78 was that "an ordinary shunt-wound motor" was self-regulating.

In the large Brush dynamo shown in Plate 23 attention had been drawn by Mr. Crompton (page 132) to what he thought was the weakness of the shaft and the shortness of the bearing to take the strain of the belt. But in comparing this with his own dynamo he had omitted to enquire into the difference of the speeds at which the two machines were intended to run. If this were taken into account, the criticism would fall to the ground.

The Parsons turbo-electric generator referred to by Mr. Cochrane (page 133) was undoubtedly an ingenious invention, and from its compactness was suitable as a generator in certain cases. Its efficiency however he understood was far behind that of a good steam engine; some tests he had seen showed a consumption of more than 60 lbs. of steam per horse-power per hour.

In the application of electricity to underground pumping in mines he had not contemplated small portable pumps, such as those referred to by Mr. Davey (page 138); but he had in view projects for several extensive pumping plants, one of which was for lifting 500 gallons per minute to a height of 200 fathoms, and he saw no difficulty in doing this work by electricity. He did not agree that hydraulic pumping must be more efficient, taking into account the power lost in the main pump, together with the loss by friction in the pipes and bends. It was difficult to get at the efficiency of hydraulic pumping, with a full statement of the details, such as was

given in page 83 respecting the electric pumping at Normanton; and strange views were sometimes entertained on the subject. In addition to the loss by friction in forcing water through a pipe, he would point out that there was always a certain amount of air which found its way into the mains, and that the compression of this air was an additional source of loss.

There was no reason why motors should run at so high a speed as 1000 revolutions per minute; they could be supplied to run at only 200 revolutions or even less; and the designing of suitable gearing to reduce this speed to that of the pump should not be a serious obstacle. It was also to be remembered that an engine driving a dynamo would run at a high speed; and it seemed probable therefore that, owing to a more efficient consumption of steam than could be obtained in a slow-speed engine, the loss in speed-reducing gear might be fully compensated.

The figures of the working expenses given in page 101 of the paper had been furnished to him by Messrs. Jager themselves. The four items—"lamp renewals," "oil, waste, and sundries," "repairs, including men's time attending dynamo," and "gas consumed on Sundays,"—he was informed were taken from their books for the year named. The power required from the engine for driving the dynamo was merely calculated, and therefore the coal consumption was also calculated; the dynamo was driven by a large engine which was driving other machinery also; and the allowance of 3 lbs. of coal per HP. per hour was considered a liberal calculation. He did not mean to say that in every instance a saving could be effected by the substitution of electric lighting; in such a case as Messrs. Jager's the engine and boilers were in use whether the dynamo was there or not; it cost nothing extra for firemen's wages, and the extra wear and tear of the engine and boilers might be neglected. If however the power were reckoned at one farthing per horse-power per hour, which was a liberal allowance in Leith for all charges, including labour, fuel, oil, and depreciation on engines and boilers &c., it would cost £42 for the 40,000 horse-power hours which he calculated were absorbed in the electric lighting throughout the year. And substituting this in place of the £12 calculated by Messrs. Jager for coal, the yearly

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saving though reduced would still amount to £113, even while allowing so liberal a charge for horse-power.

The President considered it was an advantage to the Institution to have such a summary as the present paper had furnished of what had been done in electric engineering, because it had enabled the subject to be taken up in all its branches in the discussion. It had also shown that England need not be ashamed of her electrical engineers, who were going to find a very large amount of work for mechanical engineers in the future. One question for the future was whether electric lighting was going to drive gas works to use their gas for other purposes than lighting; and it had been remarked (page 117) that it was cheaper to burn the coal under a boiler for raising steam in order to create an electric current than to distil it in a gas retort. But the gas manufacture had this advantage, that it left numerous residuals, none of which could be got from coal burnt under a boiler; and the gas itself could be supplied at a very low charge, if a fair price were got for the residuals. It was this which had kept the gas works going, and had enabled them, notwithstanding all the improvements in electric lighting, to go on paying higher dividends. The question for electric engineers was therefore what could they do in competition with gas for lighting houses and streets with commercial success. All the Members he was sure would join in a hearty vote of thanks to Mr. Geipel for his paper, which had given rise to so useful a discussion.

Mr. E. B. Ellington wrote to enquire the basis of the calculations in the compilation of Tables 1 and 2, pages 85 and 86, which were intended to prove the relative superiority of electricity over other means of transmitting power to a distance. What items were included in the cost? What were the working pressures assumed, the sizes of pipes and cables, and the efficiencies? The cost of hydraulic power given in Table 2 did not agree with the experience

of the London Hydraulic Power Co., which was supplying a large amount of power through a length of 26 miles of mains from the central pumping station at a charge in many cases of considerably less than fourpence per horse-power per hour, including profit; the greatest distance the water had to travel through the mains from the pumping station to any place of application was not more than four miles. From the experience of supplying hydraulic power from central stations in Hull and London, he considered it highly improbable that any system of public distribution of power in towns would admit of a lower charge than £20 per horse-power per annum, which was at the rate of twopence per horse-power per hour. With a water pressure of 700 lbs. per square inch the efficiency of the pumping engines was 80 per cent.; and the loss of pressure in the mains if well laid out was not more than 2 per cent. per mile. In London there were between 600 and 700 machines working from the 26 miles of mains, and about 95 per cent. of the power delivered into the mains was registered by meters measuring the exhaust water discharged from the machines; he therefore failed to see how any other method of transmission could be expected to give greater efficiency. No general rule he considered could be laid down as to the relative advantages of various systems of distribution. Moreover theoretical efficiency was often not the most important element in determining what method of distribution of power to adopt for any particular case; for each method had its own suitable applications.

Mr. THOMAS INSTONE wrote to ask about the silicium-bronze wire which was mentioned in page 87 as having been used for the long span of 130 yards, presumably because its tenacity was supposed to be higher than that of copper. If its conductivity was the same as copper, why was it not used throughout the entire line? Copper wire itself however could now be so treated as to possess a tenacity of 30 tons per square inch with an elongation of less than one per cent. under the breaking load; he had had a dead weight of 340 lbs. suspended by a copper wire of No. 14 Imperial W. G. or 0·080 inch diameter, having a sectional area of 0·0050265 square inch, which was just equal to 30 tons per square inch. Although

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the wire was so hard as to show so small an elongation, it was not brittle; it could be coiled round its own diameter, uncoiled, coiled again, and in some cases even uncoiled a second time, without breaking. The same wire if annealed would exhibit not less than 35 to 40 per cent. elongation before fracture, and a tenacity not exceeding 15 tons per square inch. The wire was of very high conductivity, having an electrical resistance not greater than Matthiessen's standard for pure copper wire.

Mr. Geipel wrote, in reply to Mr. Ellington's enquiry (page 148), that Tables 1 and 2, pages 85 and 86, were based upon investigations made by Herr Beringer,* as mentioned in page 85. Professor Grove's valuation of the cost of power was the basis taken by Herr Beringer as the cost of steam power: namely small steam engines 3·8 pence per HP. per hour, medium size 2·63 pence, and large steam engines 1·02 pence per HP. per hour; these calculations included interest, depreciation, and attendance. As regarded water power, Herr Beringer had adopted Meissner's estimate, according to which the cost of water power was one-fifth to one-tenth of that of steam power. Very complete information on the subject would be found in Mr. Kapp's work referred to in page 85.

In regard to Table 2 not agreeing with the experience of the London Hydraulic Power Co. (page 149), who were supplying power at considerably less than fourpence per horse-power per hour, while the greatest distance the water travelled was not more than four miles from the pumping station, he presumed that in that case two miles or 3,520 yards might be assumed to be the average distance. On referring to Table 2 it would be seen that the cost of transmitting 100 HP. over 1,100 yards by hydraulic power was 1·78 pence per HP. per hour, and over 11,000 yards 4·15 pence; therefore the cost for a distance of 3,520 yards would be somewhere between these two prices, and would consequently be well within the fourpence per HP. per hour above mentioned. When it was further said that

* Kritische Vergleichung der elektrischen Kraftübertragung mit den gebräuchlichsten mechanischen Uebertragungssystemen, von A. Beringer. Berlin 1883.

95 per cent. of the power delivered into the mains was registered by meters measuring the exhaust water, he presumed by the word power was meant water, and that this 5 per cent. of loss was due to leakage alone; and if the average length of main were two miles, the average leakage per mile would be $2\frac{1}{2}$ per cent. The loss by pressure and leakage together would then be $2+2\frac{1}{2}=4\frac{1}{2}$ per cent. per mile, assuming that the mains were well laid out; and in four miles of mains the power lost would be $4\frac{1}{2} \times 4 = 18$ per cent. But in addition to this loss there was the power lost in the hydraulic machines; it was not stated by what percentage this was represented; yet this was the most important loss in hydraulic transmission where varying loads were to be worked. The question was how much of the power indicated in the cylinders of the pumping engine was represented by actual work done by the hydraulic machines in practical use; and not how much of the water pumped into the mains was exhausted from the machines, because the water might be exhausted without any useful work being done. An electric motor drew its current from the mains fairly in proportion to the work it was doing. Was this the case with the hydraulic motors used in the London hydraulic system?

In the Solothurn transmission (page 87) he presumed the reason why silicium-bronze had not been used throughout was because it would have cost more. He agreed with Mr. Instone (page 149) that hard-drawn copper as now made was admirably adapted for long spans.

Since the discussion upon his paper he had visited the Portrush and the Bessbrook and Newry tramways by the kind invitation of Mr. Traill and Mr. Barcroft, and had paid particular attention to the driving gear. In regard to the difficulty referred to by Mr. Smith (page 127), he found that the pitch-chains were giving the greatest satisfaction at Bessbrook. Mr. Barcroft had reported to Dr. Edward Hopkinson that one of the chains made by Mr. Hans Renold had been put on on 13th July 1887, and the locomotive had since run about 6,000 miles, drawing trains of 9 to 27 tons gross weight; the chain had not been off, nor had it been tightened; in fact it showed little signs of wear, which result was no doubt due to the new method of

(Mr. Geipel.)
oiling, as well as to the strength of the chain. There was no noticeable noise in the working of the gear on either of these railways; and the success of both exceeded his own most sanguine expectations.

MEMOIRS.

JOSEPH ARMSTRONG was born at Wolverhampton on 14th August 1856, being the third son of the late Mr. Joseph Armstrong, chief superintendent of the locomotive and carriage department of the Great Western Railway. After being educated at the Royal High School, Edinburgh, he entered the Swindon works of the Great Western Railway as an engineering pupil. He early showed great mechanical ingenuity, and was employed on various important works. For some years his time was devoted almost entirely to the improvement of the automatic vacuum brake now applied to the whole of the passenger stock on the Great Western Railway. In the details of the brake apparatus he introduced improvements in the automatic guard's-valve or brake-setter, and in the application of the automatic brake to slip carriages. He also devised a marine log, and various improvements in locomotive construction, including blast-pipes and a plan of continuous exhaust. In January 1884 he was appointed district superintendent of the locomotive and carriage department of the Great Western Railway, Swindon; and in July 1885 was removed to Wolverhampton, as assistant superintendent of the northern division of the Great Western Railway. Having been in indifferent health for some time, he died at Wolverhampton on 1st January 1888, at the age of thirty-one. He became a Graduate of this Institution in 1878.

FRANCIS HENRY BEATTIE was born in Liverpool on 1st October 1843, and served his apprenticeship at Nine Elms, London, under his uncle, the late Mr. Joseph Beattie, locomotive superintendent of the London and South Western Railway. Subsequently he was occupied specially in the construction of roofs and bridges; and designed and superintended the manufacture and erection of many

important roofs and buildings in this country and abroad, for which the use of mild steel was largely adopted. He was perfecting his invention of a particular kind of torpedo when he was overcome by illness which resulted in his death, at Bowdon, near Altrincham, Cheshire, on 31st December 1887, at the age of forty-four. He became a Member of this Institution in 1882.

William Barber Buddicom. In the memoir given in page 466 of last year's Proceedings the two following corrections are desired by his son, having escaped observation in the revision of the memoir for publication in the Institution Proceedings.

The system of premiums to engine drivers for economy in consumption of fuel and oil, which was introduced by Mr. Buddicom on the Grand Junction Railway, had it is understood been carried out previously on the Liverpool and Manchester Railway.

The original Crewe outside-cylinder engines of 1840 were introduced by Mr. Locke and Mr. Buddicom on the Grand Junction Railway, while Mr. Buddicom was the locomotive superintendent of that line; and subsequently in France on the Paris and Rouen Railway and other lines.

Edward Forster was born at Blyth, Northumberland, on 18th December 1813. He was engaged at the Blyth Alkali Works from two to three years, and afterwards at the Jarrow Chemical Works on the Tyne till 1843, when he was appointed by Messrs. Chance to manage their chemical works which were then situated at Spon Lane, near Birmingham, in connection with their glass works. The duty being taken off glass in 1845 necessitated the enlargement of the glass works and the removal of the chemical works to another site; and he was then engaged in the building of additional glass furnaces at the Spon Lane Glass Works, and finally in the re-construction of all the furnaces on the Siemens regenerative principle, which was accomplished in 1865 and proved a commercial success. As Messrs. Chance were the first glass manufacturers who successfully adopted this principle in their furnaces, the work of re-construction required great skill and patience; and the success of the experiment on so

large a scale reflects much credit upon the enterprise which prompted the adoption of the plan, and upon the painstaking efforts of Mr. Forster in superintending the work throughout. In 1860 he became general manager of the glass works, and continued to occupy this important position until his death, which occurred on 12th October 1887, after a short illness, in the seventy-fourth year of his age. A memorial window placed by Messrs. Chance in St. Paul's Church, West Smethwick, marks their sense of his character and of the high value of his services. He became a Member of this Institution in 1861.

Sturges Meek, the youngest son of Mr. Richard Meek, of Dunstall Hall, Staffordshire, was born on 9th April 1816. He commenced his engineering career in 1833 as a pupil of George Stephenson on the London and Birmingham Railway, and was afterwards assistant to Robert Stephenson on the same line, remaining with him until its completion. His next work was in connection with a line from York to Newcastle, when he was stationed at Newton-on-Ouse. In 1841 he was appointed by Mr. Locke as one of the resident engineers on the Paris and Rouen Railway, his section being at the Rouen end; and on the completion of the works he was engaged by Mr. Locke to lay out the direct London and York Railway. Towards the end of 1844, when Mr. Locke's connection with that railway ceased, the company desired to retain Mr. Meek as engineer; but he preferred to remain with Mr. Locke, by whom he was afterwards sent to Holland with reference to the Dutch Rhenish Railway. On his return he was engaged with Mr. Locke in laying out several new lines for the London and South Western Railway in the neighbourhood of Goodwood, Andover, Guildford, Chichester, &c. His next work was getting up the parliamentary plans for the Derby and Crewe line, which were passed in 1846, the line being taken over in the same year by what is now the North Staffordshire Railway. He was then appointed by Mr. Locke resident engineer of the Liverpool and Preston line passing through Ormskirk, of which he carried out the entire work. He then became connected with the East Lancashire

Railway, and in 1853 was appointed engineer to the Lancashire and Yorkshire Railway, which eventually absorbed the East Lancashire. He remained engineer for both lines, having the whole responsibility of the maintenance of the line, permanent way, new constructions, new lines, and parliamentary work. This position he held until 1885, when he was appointed consulting engineer in London to the railway. From the time when at the age of seventeen he became a pupil of George Stephenson he was never out of work; he was connected with many of the great railway schemes in England, and had made the subject of permanent way a special study. He died at Kensington on 23rd February 1888, in the seventy-second year of his age. He became a Member of this Institution in 1863.

Josiah Richards was born at Dowlais on 15th November 1823, and after an apprenticeship at the Dowlais Iron Works was appointed in November 1849 chief engineer to the Ebbw Vale Works, which post he held until May 1860, being then promoted to the management of the Abersychan Iron Works, the property of the Ebbw Vale Iron Co., where he remained until December 1870. In conjunction with others he leased the Pontypool Iron and Tinplate Works, and was senior partner up to 1886; during this time he increased very much the productive power of the works. His death took place on 3rd March 1888, in the sixty-fifth year of his age, at his residence, Plâs Llecha, Tredunnoc, Monmouthshire, of which county he was a justice of the peace and deputy lieutenant. He became a Member of this Institution in 1856.

John Waddell was born in 1828 at the Gain, near Airdrie. His early life was spent with his father on the Gain farm; but while still very young he set up as a railway contractor, and for several years carried out contracts of limited extent and importance, thereby gaining the experience which led to the great success he subsequently attained. The following were the more important works carried out by himself and the firm of which he was the head:—Leadburn and Dolphinton Railway; Carstairs and Dolphinton Railway; Burntisland Sewerage Works; Cleland and

Mid-Calder Railway; Camps and Addiewell Railways; Glasgow and Coatbridge Railway; Sighthill Branch Railway; Hawthornden and Penicuick Railway; Millerhill, Loanhead, and Glencorse Railway; widening of the North Bridge, Edinburgh; Byker, Walker, and Percy Main Railway; Sunderland and Monkwearmouth Railway, including the massive iron bridge over the Wear; Leuchars and Tay Bridge Railways; new Dundee Tunnel and Station Works; East Norfolk Railways; Montrose and Arbroath Railway; Ely and Newmarket Railway; Downham and Stokeferry Railway; James Watt Dock and Harbour Works, Greenock; Tweedmouth Railway; Burndall and Yarmouth Railway; Lofthouse and Whitby Railway; Whitby and Scarborough Railway; Llanelly and Mynydd Mawr Railway; new Putney bridge across the Thames; Clapham and Putney-Hill Sewers; Mersey Railway and Tunnel Works, Liverpool; Edinburgh and South-Side Suburban Railway. He had for some time been engaged in the development of large coal-fields in South Wales; and at the time of his death was a director of many companies, occupying the chairmanship of the Burntisland Oil Company, the Northern Cable Tramways Company, and the Rosewell Gas Coal Company. He also took great interest in agricultural matters, and was president of the Bathgate Agricultural Association. In 1863 he was appointed provost of Bathgate, and two years later senior magistrate, an office which he held for ten years, until he removed to Belford Park, Edinburgh. He acted as convener of the building committee of the Edinburgh Exhibition in 1886; and as a member of the local committee for the Summer Meeting of this Institution in Edinburgh last year he gave his assistance in connection with the excursion to the Burntisland Oil Works. His death took place on 17th January 1888, in the sixtieth year of his age. He became a Member of this Institution in 1887.

PATRICK LAMBERT WEATHERHEAD was the second son of Mr. R. B. Weatherhead, solicitor and coroner for Berwick-on-Tweed, and was born there on 15th April 1848. He was educated at the local grammar school, and afterwards at University College, London,

where he studied under Professor De Morgan. Thence he went as an apprentice to Messrs. John Penn and Sons, marine engineers, Greenwich, where he remained till early in 1874, at the same time studying mathematics under Mr. Hogg of the Royal Naval School, New Cross. In May 1874 he went to Germany, as assistant engineer to the Märkisch Schlesische Maschinenbau und Hütten Actien Gesellschaft, Berlin, where he remained for nearly ten years. While there he designed and constructed, in conjunction with Herr C. Jüngermann, a number of engines for the most important vessels of the German navy, including those for the despatch vessel "Blitz." On Herr Jüngermann being appointed a director of the company, Mr. Weatherhead became chief engineer, and continued in that position until early in 1884, when in consequence of failing health he went to Mentone. Returning to Berlin he acted as a consulting engineer there for about twelve months, and then became engineer in the Stettiner Maschinenbau Actien Gesellschaft Vulcan at Stettin until January 1887, when owing to failing health he again went to Mentone and Montreux. In April he received an appointment as engineer in the works of Messrs. Portilla White and Co., Seville, Spain, taking charge of the designing and constructing department. In August he returned to Berwick-on-Tweed for a holiday; but his health utterly failed, and he died there on 12th January 1888, at the age of thirty-nine. He became a Member of this Institution in 1878.

IRRIGATING MACHINERY.

Plate 1.

Fig: 1.

Chinese Pump.

Scale 1/60th.

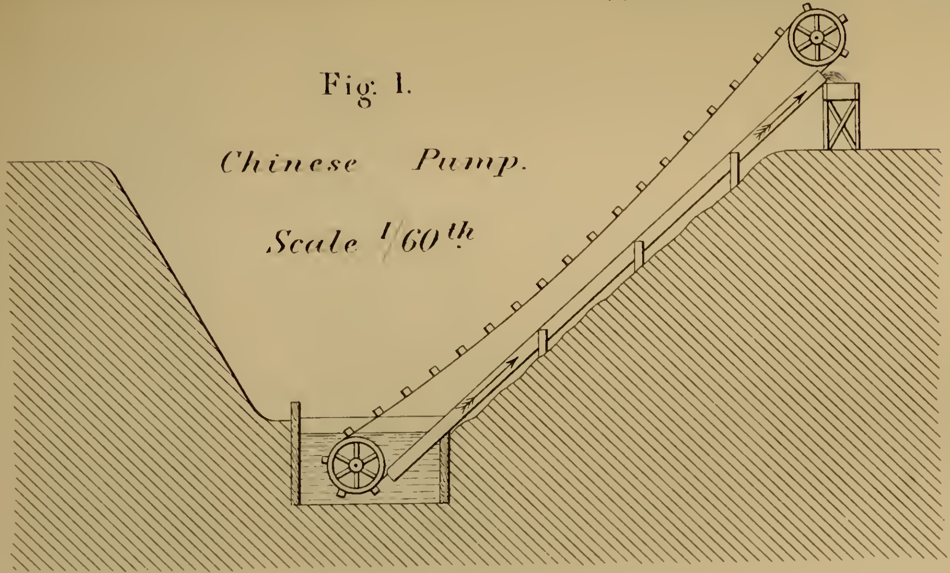


Fig: 2.

Tube-Well Pump.

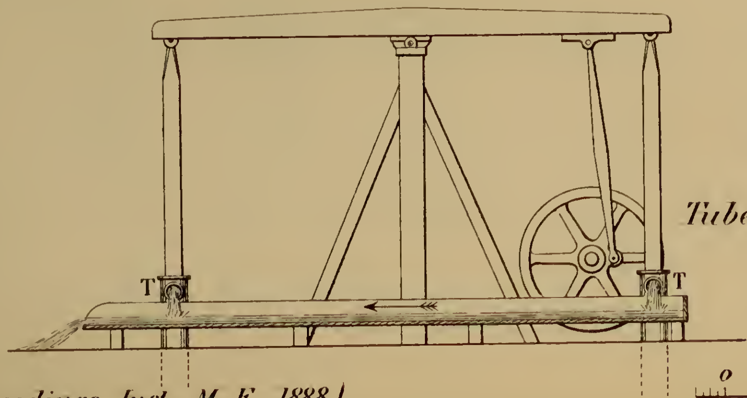
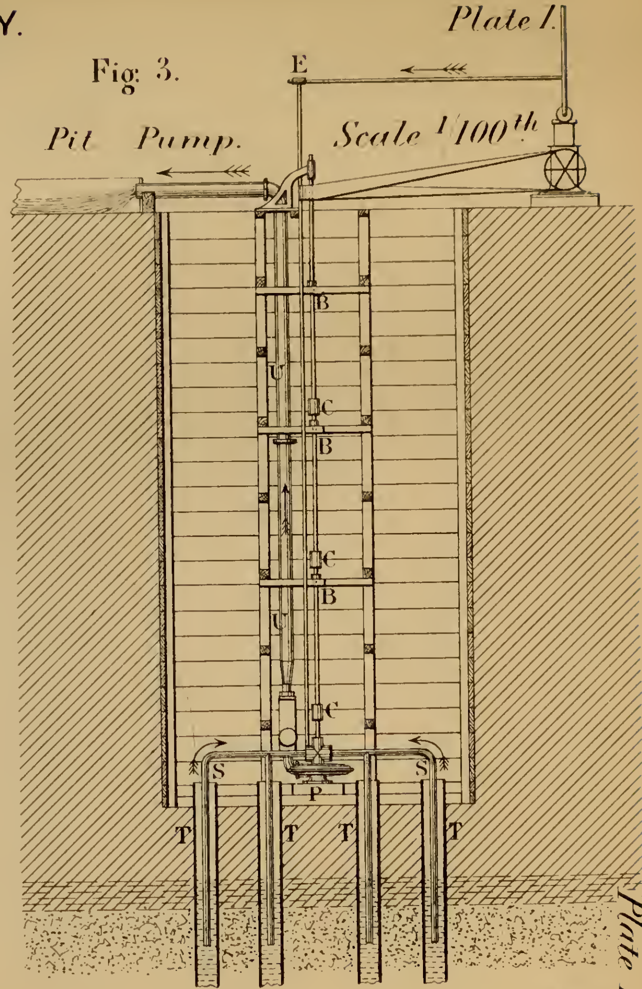


Fig: 3.

Pit Pump.

Scale 1/100th.



Scale 1/100th.

0 5 10 15 20 25 30 Feet.

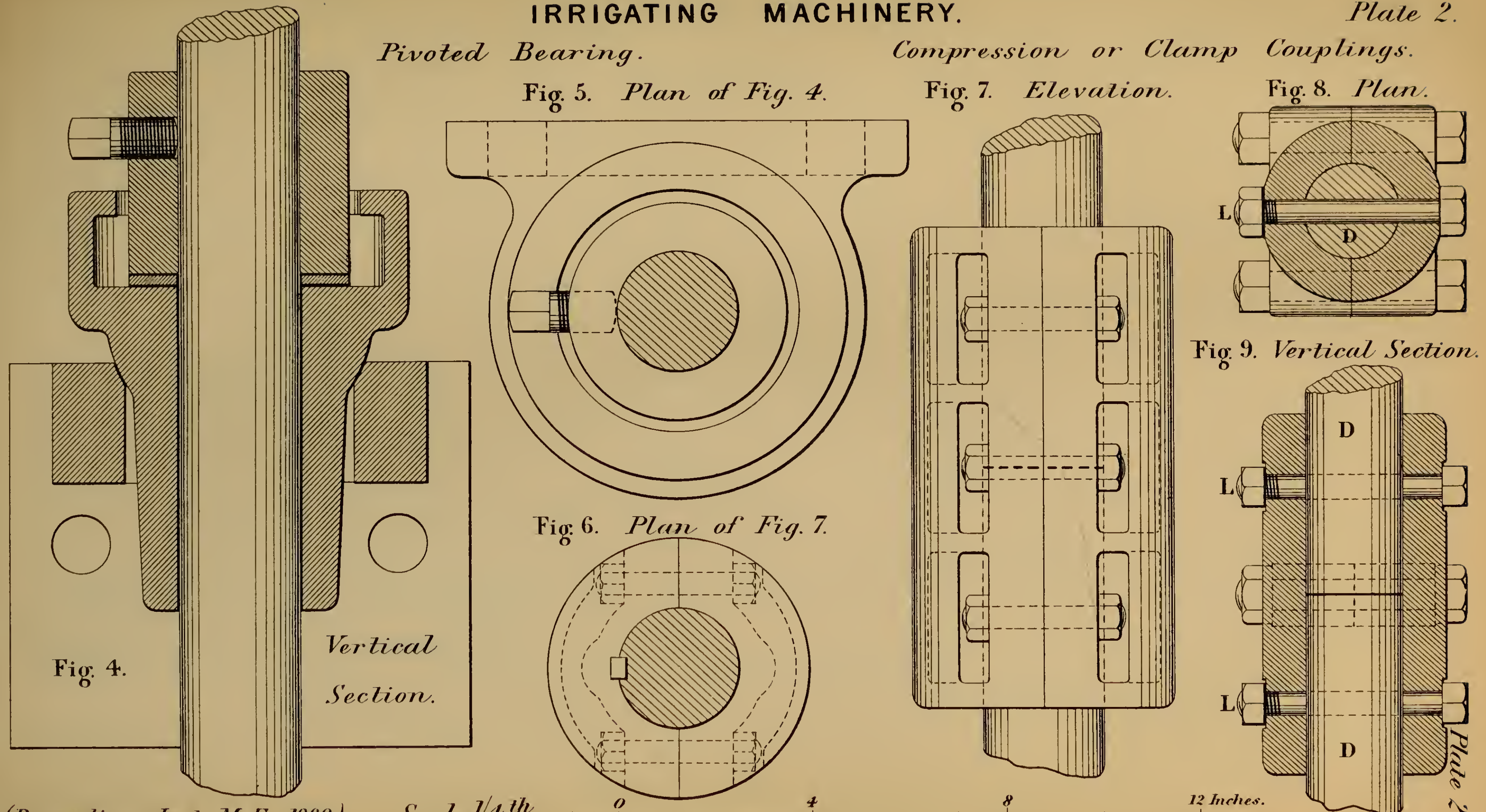
Plate 1.

(Proceedings Inst. M. E. 1888.)

IRRIGATING MACHINERY.

Plate 2.

Pivoted Bearing. *Compression or Clamp Couplings.*



(Proceedings Inst. M. E. 1888.) Scale 1/4th.

Plate 3.

IRRIGATING · MACHINERY.

Centrifugal Pump with Shrouded Wheel.

Fig. 10.

Vertical Section.

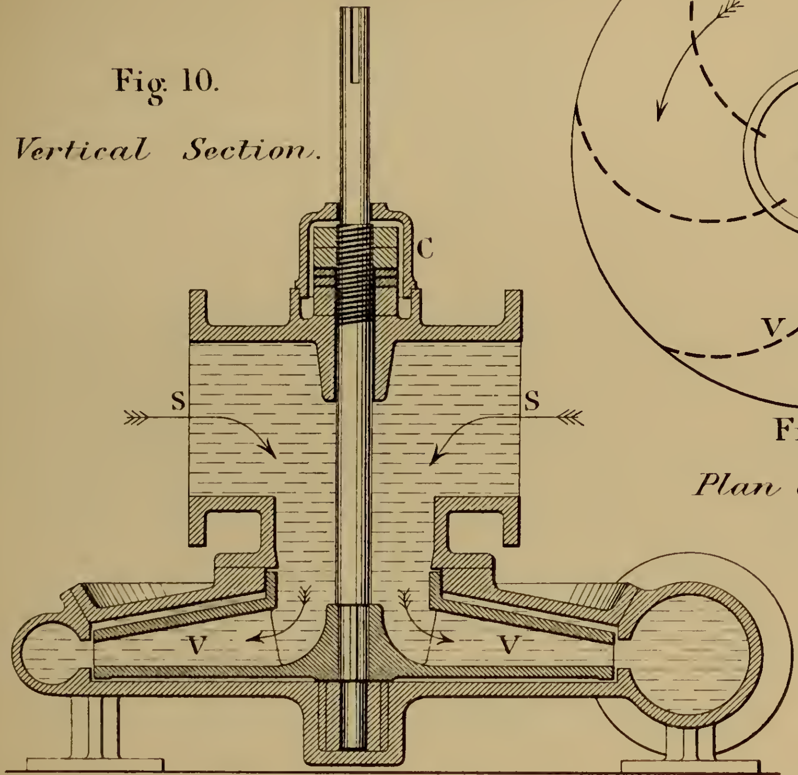
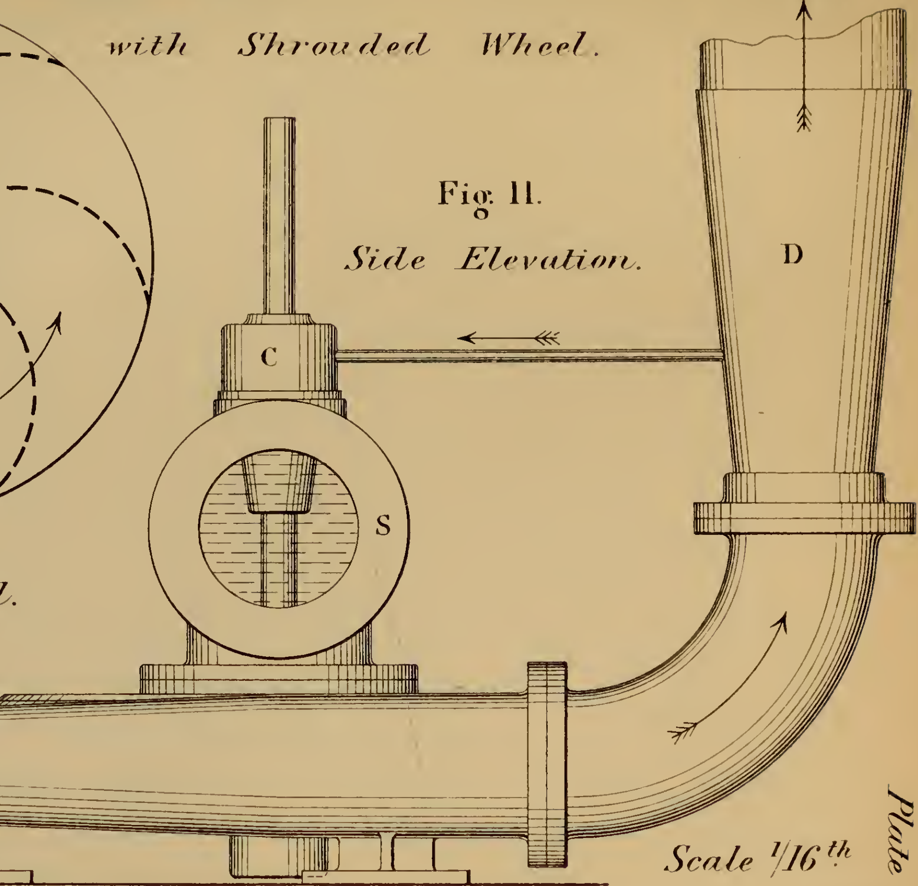


Fig. 12.

Plan of Wheel.

Fig. 11.

Side Elevation.



Scale 1/16th.

Ins. 12 6 0 1 2 3 4 5 6 Feet.

(Proceedings Inst. M. E. 1888.)

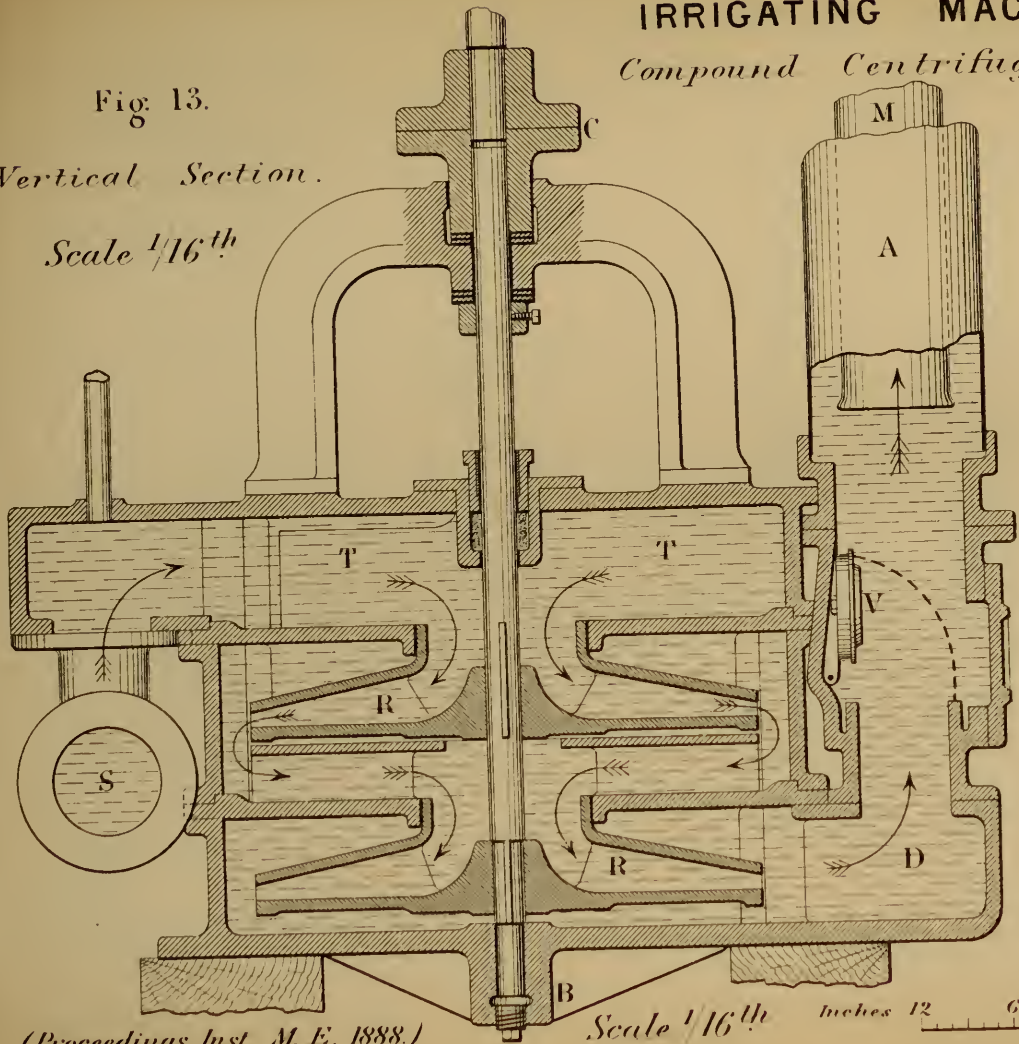
Plate 3.

Plate 4.

IRRIGATING MACHINERY.

Compound Centrifugal Pump.

Fig. 13. Vertical Section. Scale 1/16th



Scale 1/16th

Fig. 14. End Elevation. Scale 1/32nd

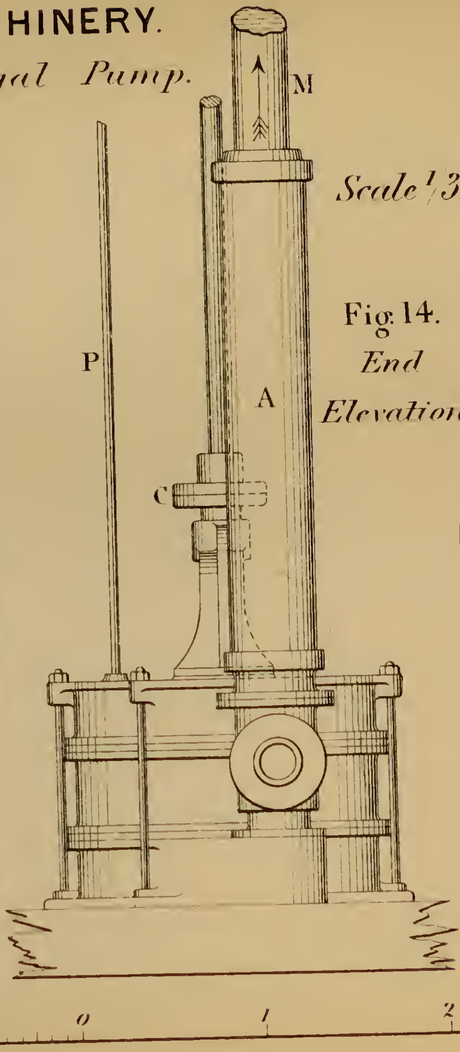


Fig. 16. Plan of Wheel.

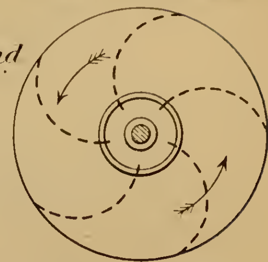
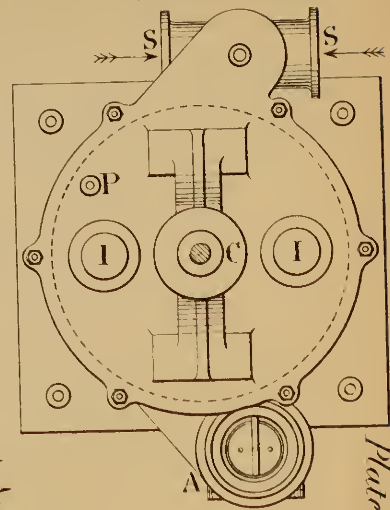


Fig. 15. Plan.

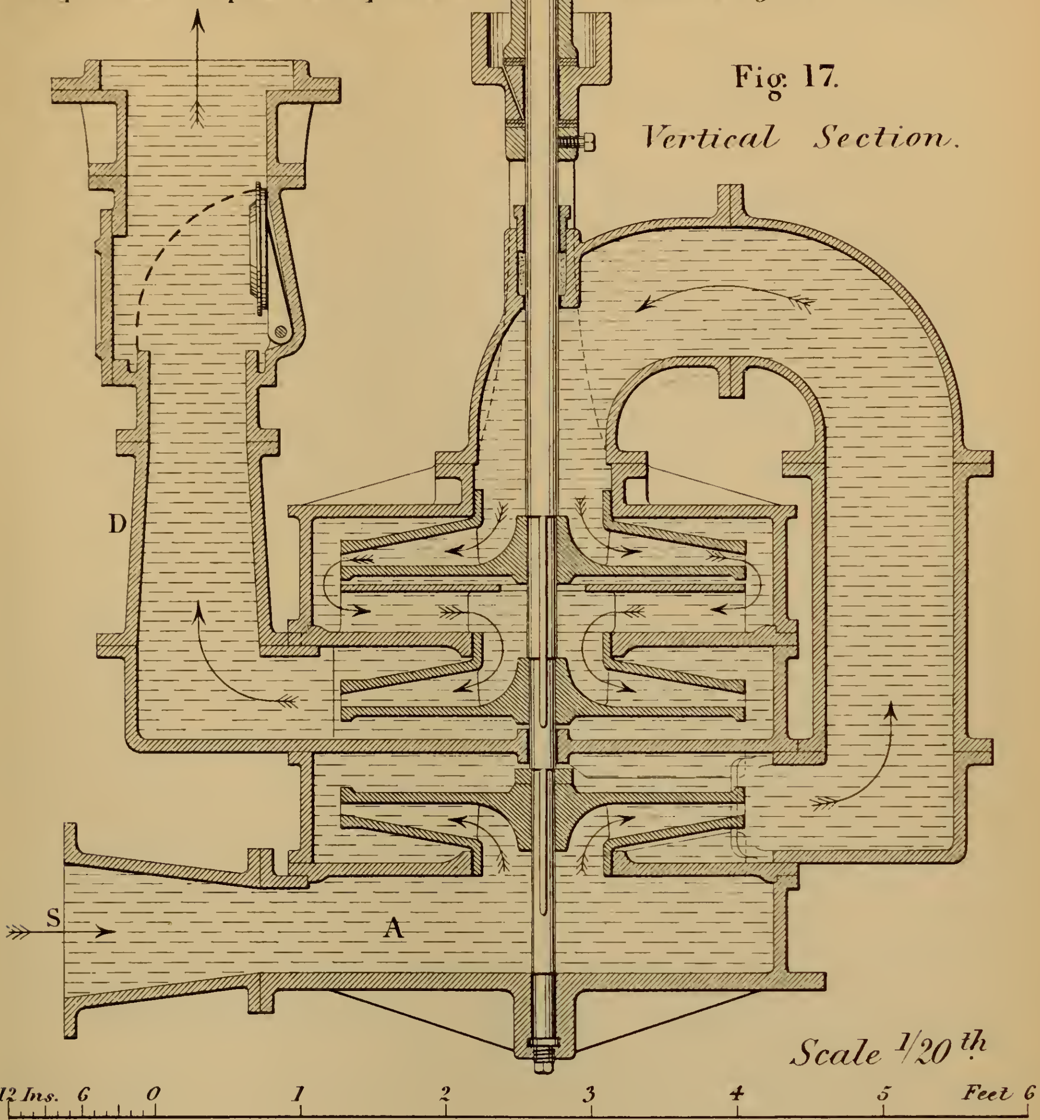


(Proceedings Inst. M. E. 1888.)

Plate 4.

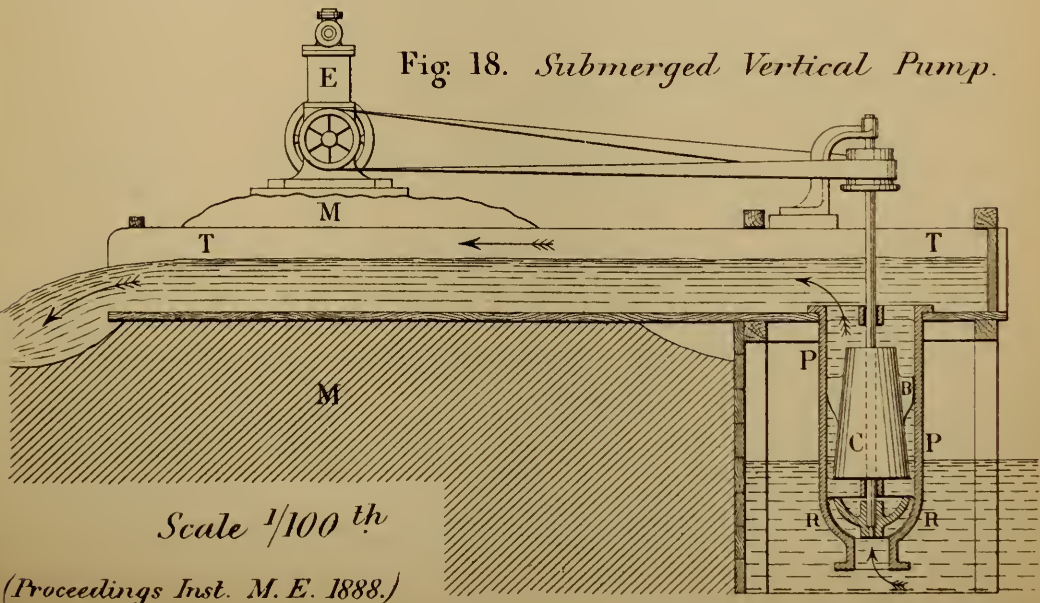
Proposed Triple Compound Centrifugal Pump.

Fig. 17. *Vertical Section.*



Scale 1/20th.

Fig. 18. *Submerged Vertical Pump.*



Scale 1/100th

(Proceedings Inst. M. E. 1888.)

IRRIGATING MACHINERY.

Balanced Centrifugal Pump with single lateral inlet.

Fig. 19.
Side Elevation with suction pipe removed.

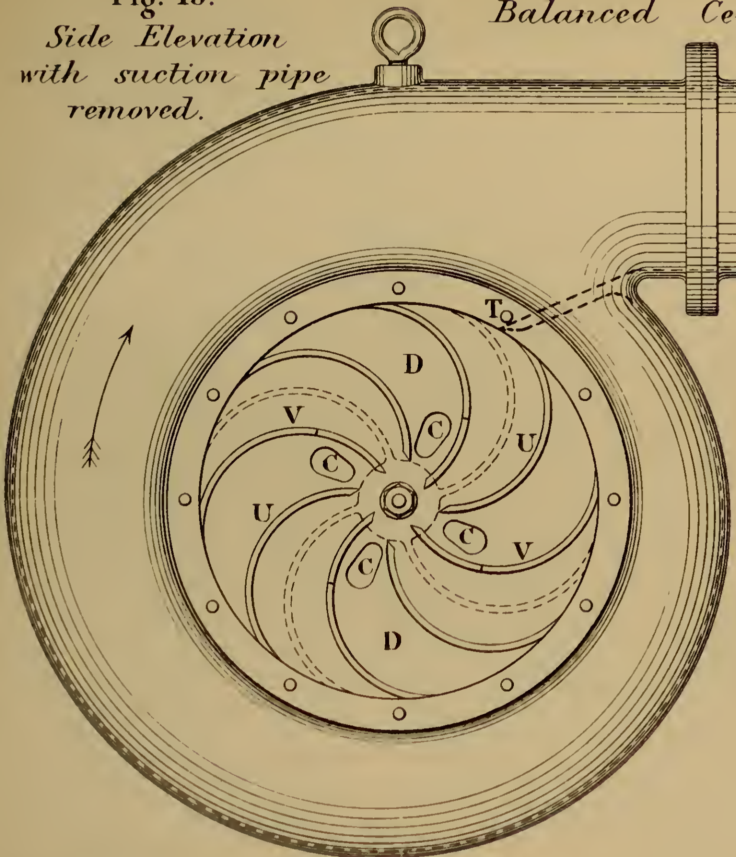
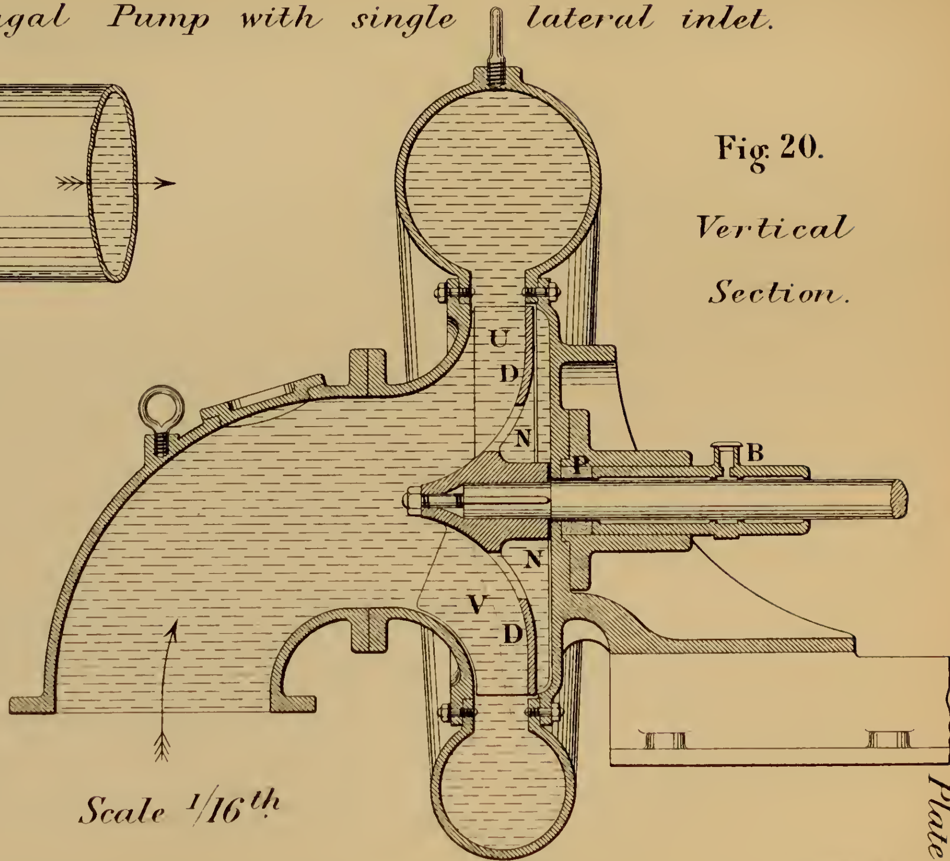


Fig. 20.
Vertical Section.



Scale 1/16th.

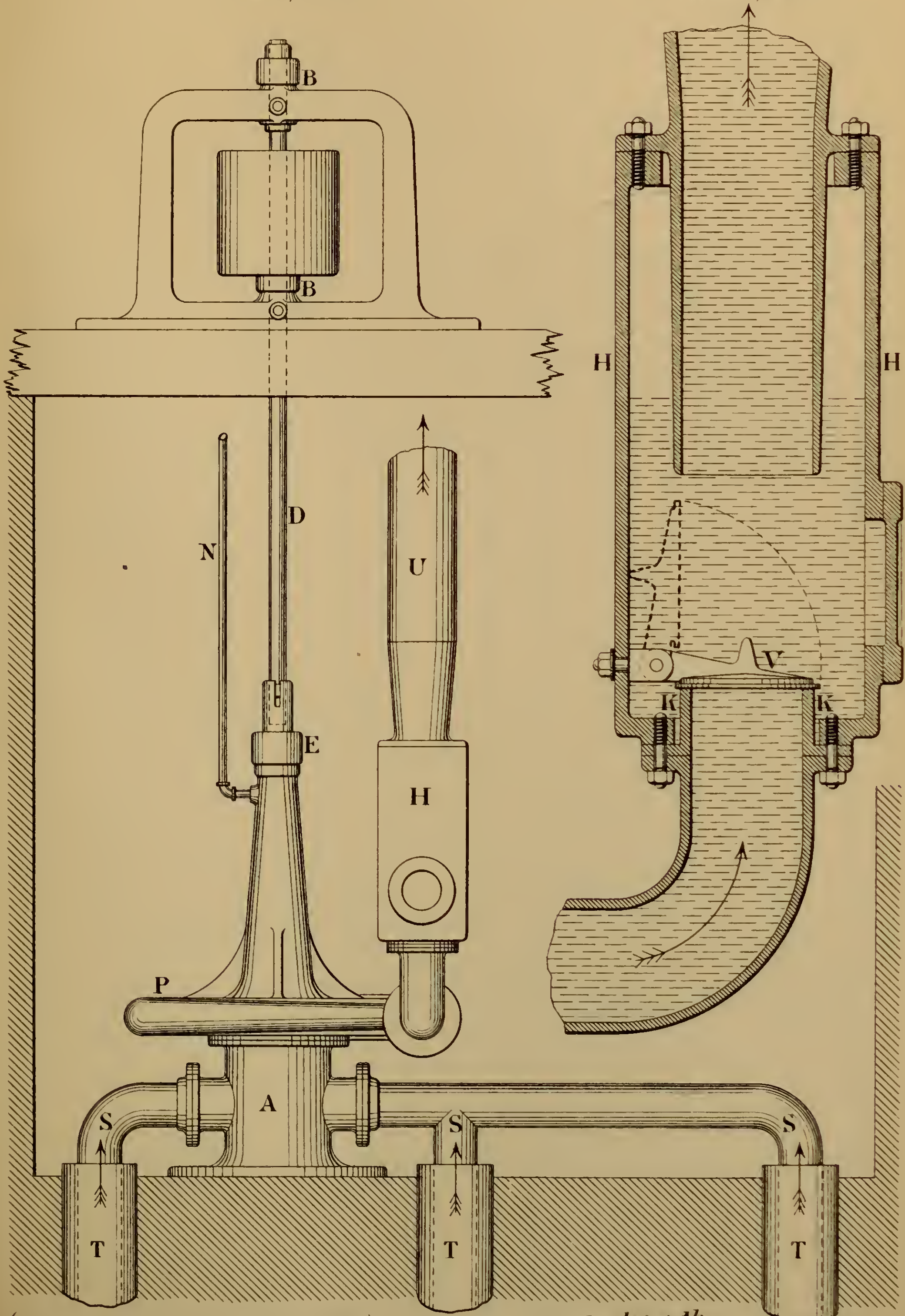
12 Ins. 6 0 1 2 3 4 5 Feet 6

Plate 6.

Improved Pit Pump.

Fig. 21.
Elevation.
Scale 1/24th.

Fig. 22.
Section of Air-vessel.
Scale 1/8th.



Scale 1/24th.

12 Ins. 0 1 2 3 4 5 6 Feet 7

Fig. 23. *Reclamation Pump.*

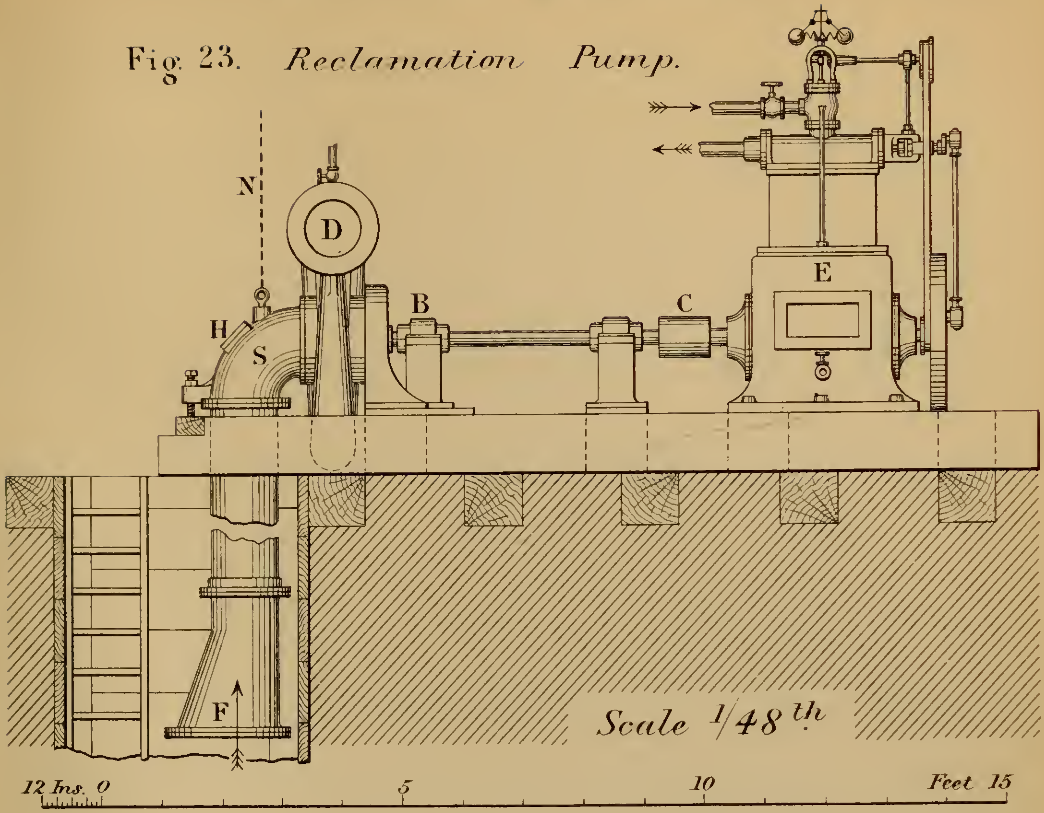
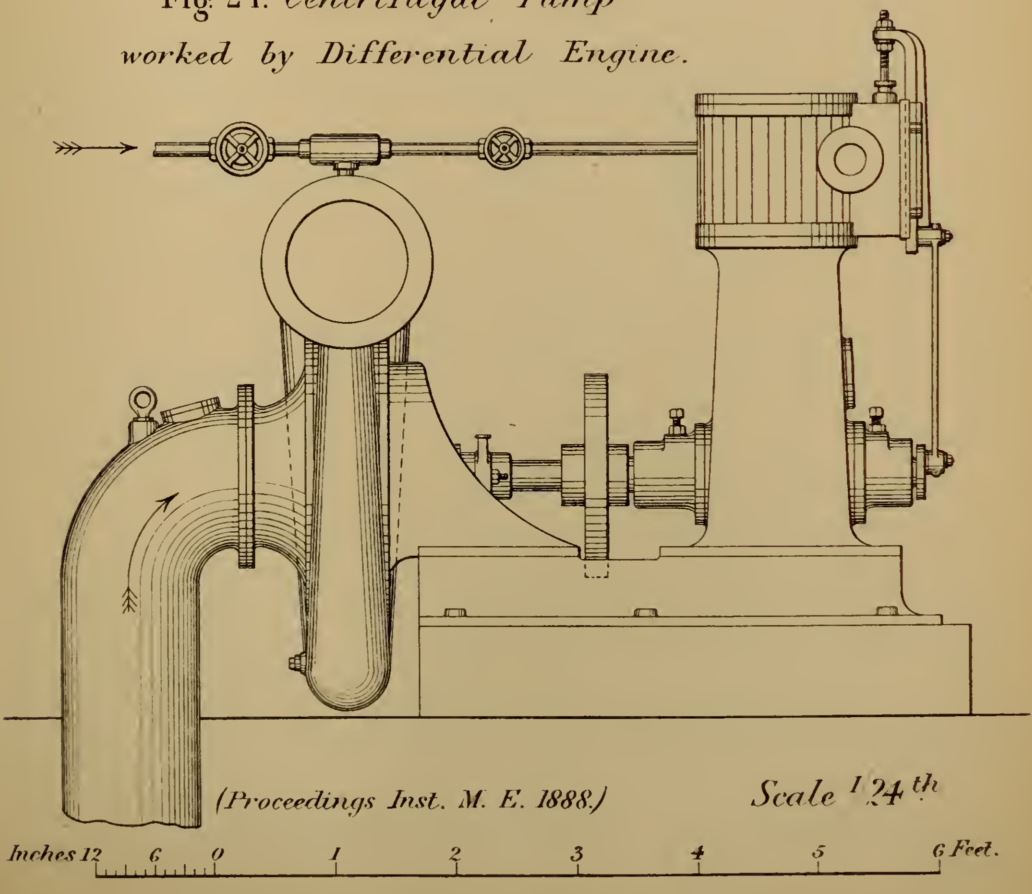


Fig. 24. *Centrifugal Pump worked by Differential Engine.*



(Proceedings Inst. M. E. 1888.)

Bulkhead Centrifugal Pumps.

Fig: 26.

Plan of Vanes.

Scale 1/10th.

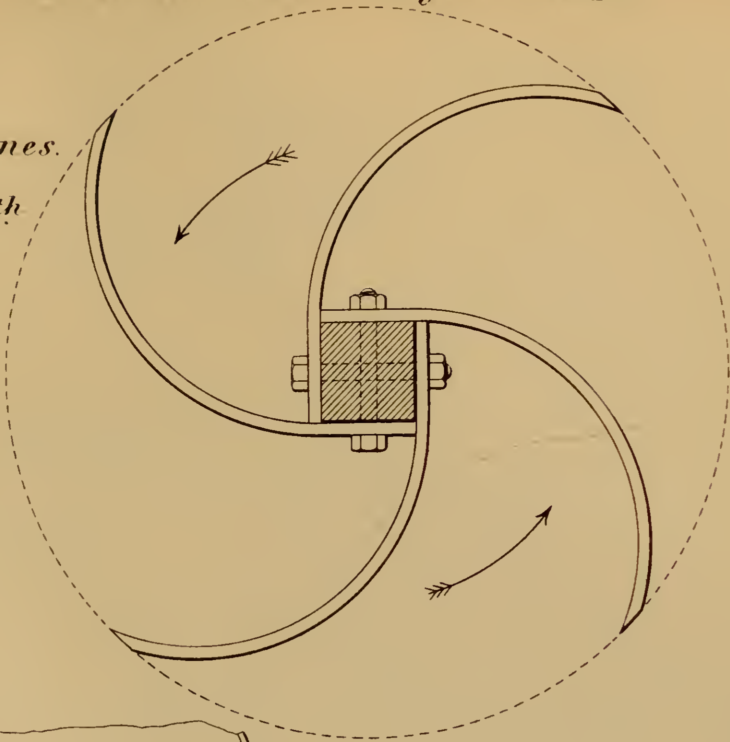


Fig: 25. *Plan of Pumps.*

Scale 1/60th.

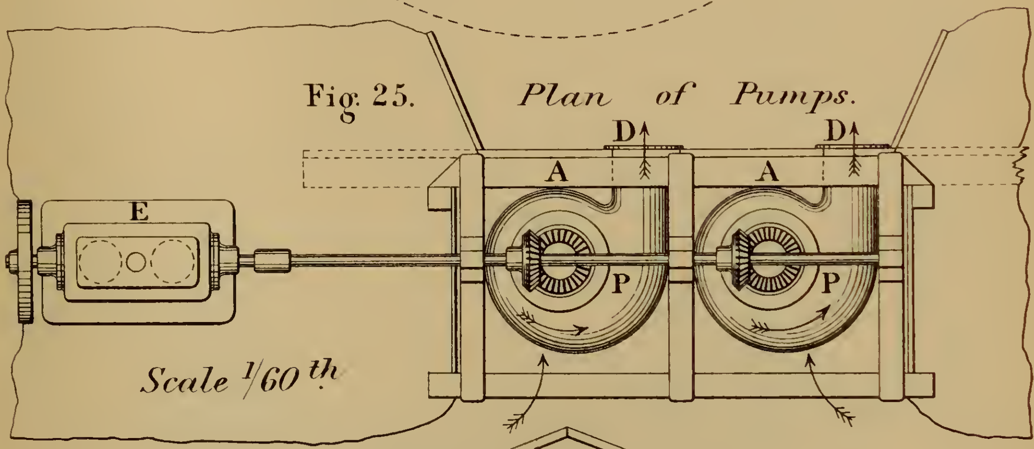
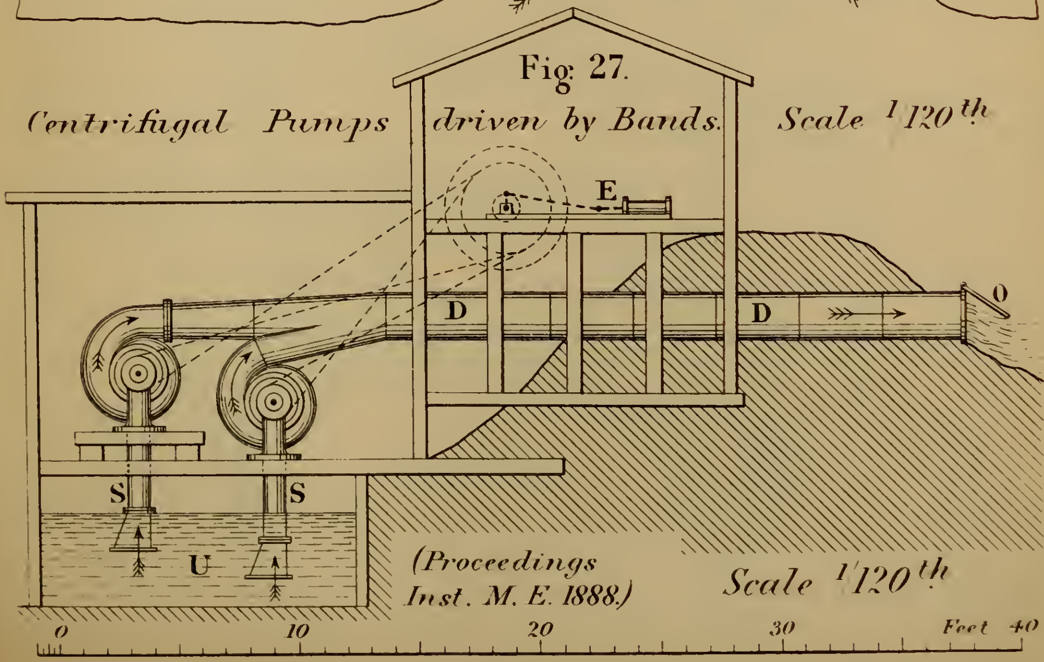


Fig: 27.

Centrifugal Pumps driven by Bands. *Scale 1/120th.*



(Proceedings Inst. M. E. 1888.)

Scale 1/120th.

IRRIGATING MACHINERY.

Single-acting Engine.

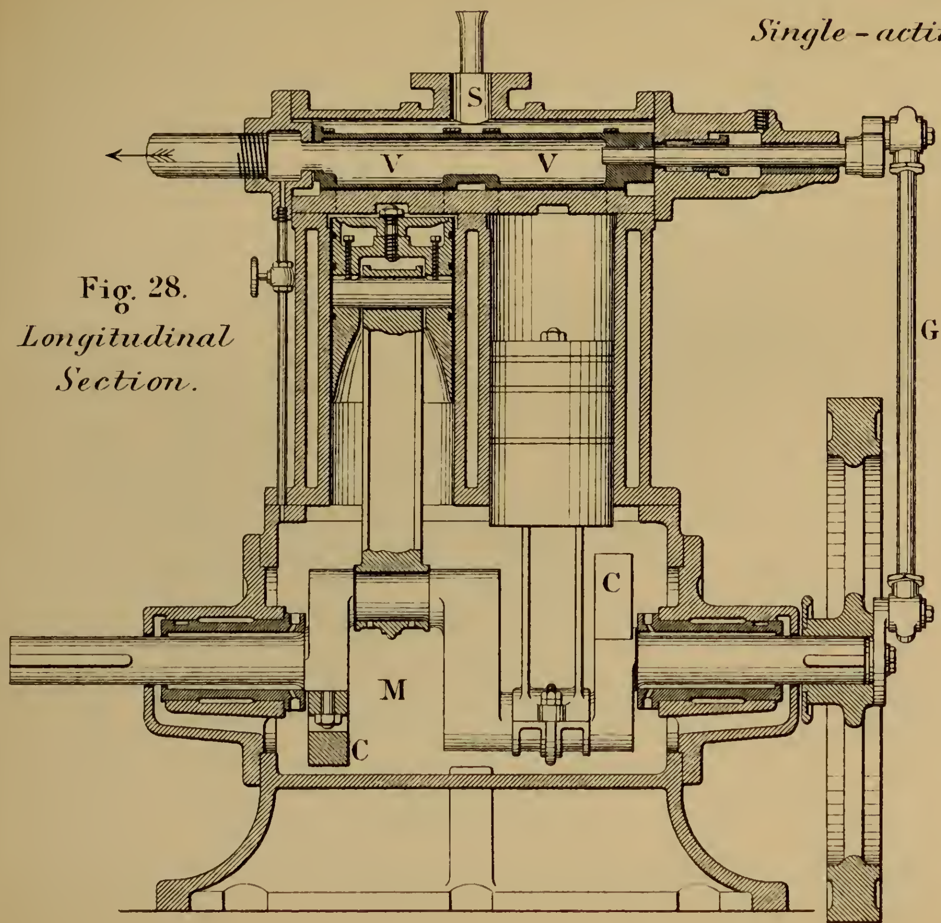


Fig. 28.
Longitudinal Section.

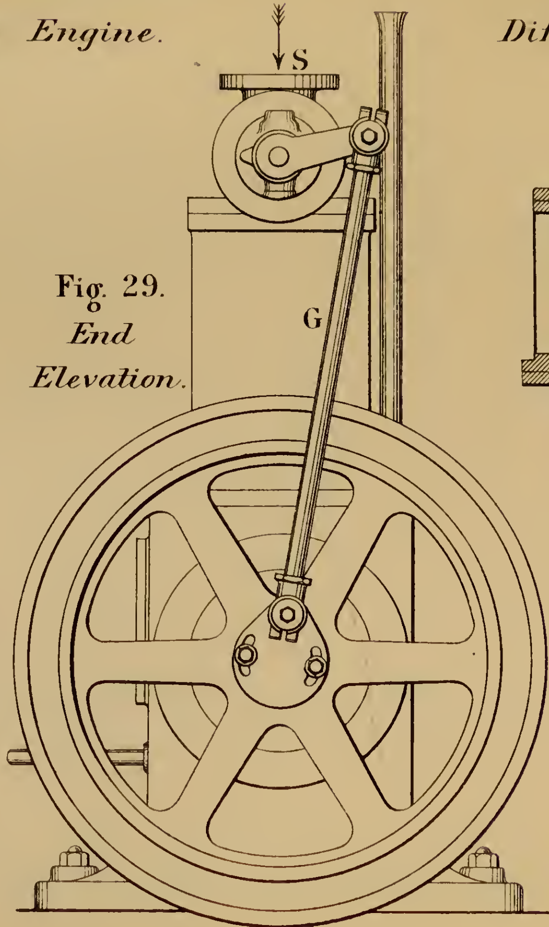


Fig. 29.
End Elevation.

Differential Engine.

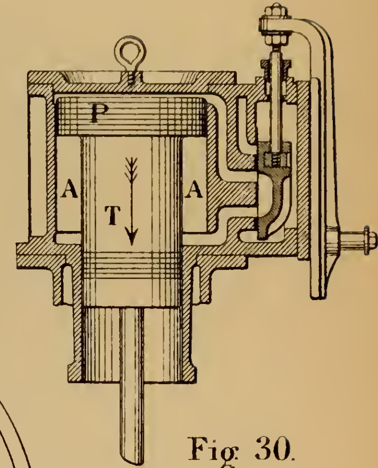


Fig. 30.
Vertical Section.
Scale 1/16th.

(Proceedings Inst. M. E. 1888.) *Scale 1/16th.*

Ins. 12 6 0 1 2 3 4 Feet.

Plate 10.

Hydraulic Rams

with automatic escape valves.

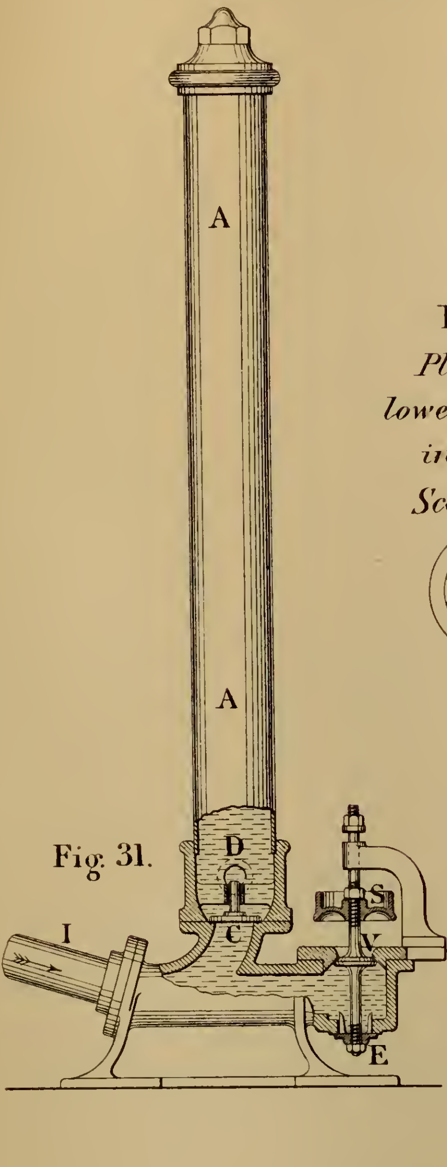
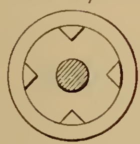
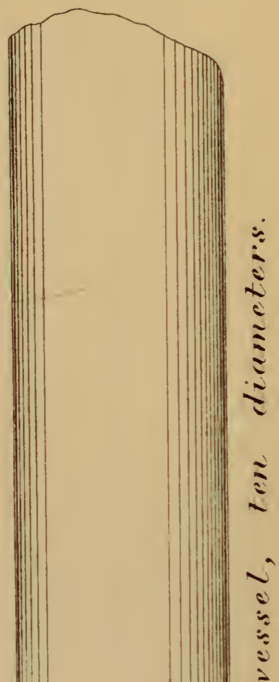


Fig. 31.

Fig. 32.
Plan of
lower valve E
in Fig. 31.
Scale 1/4th.





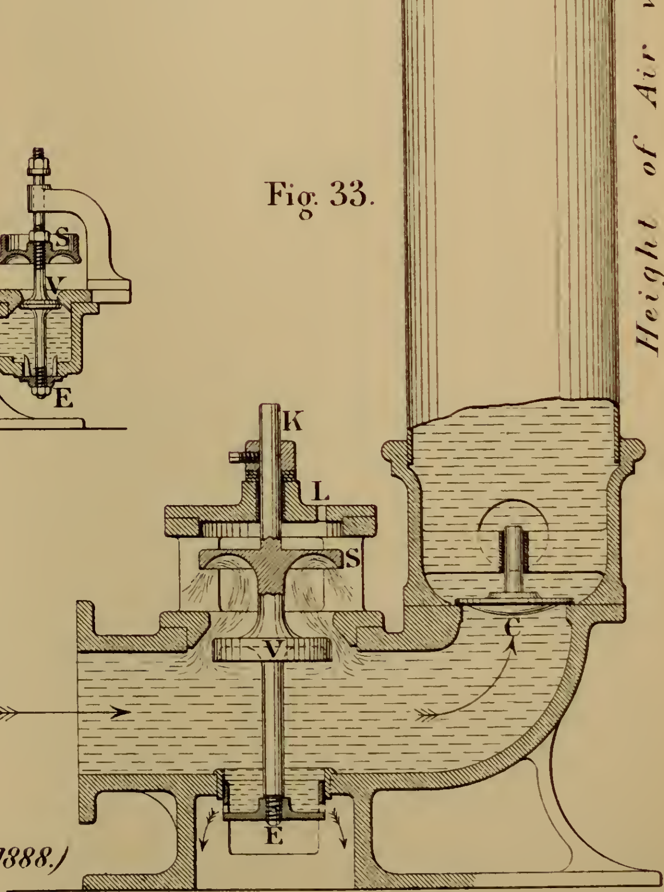


Fig. 33.

Scale 1/12th.

(Proceedings Inst. M. E. 1888.)

Inches 12 6 0 1 2 Feet.

IRRIGATING MACHINERY.

Hydraulic Ram with valve worked independently.

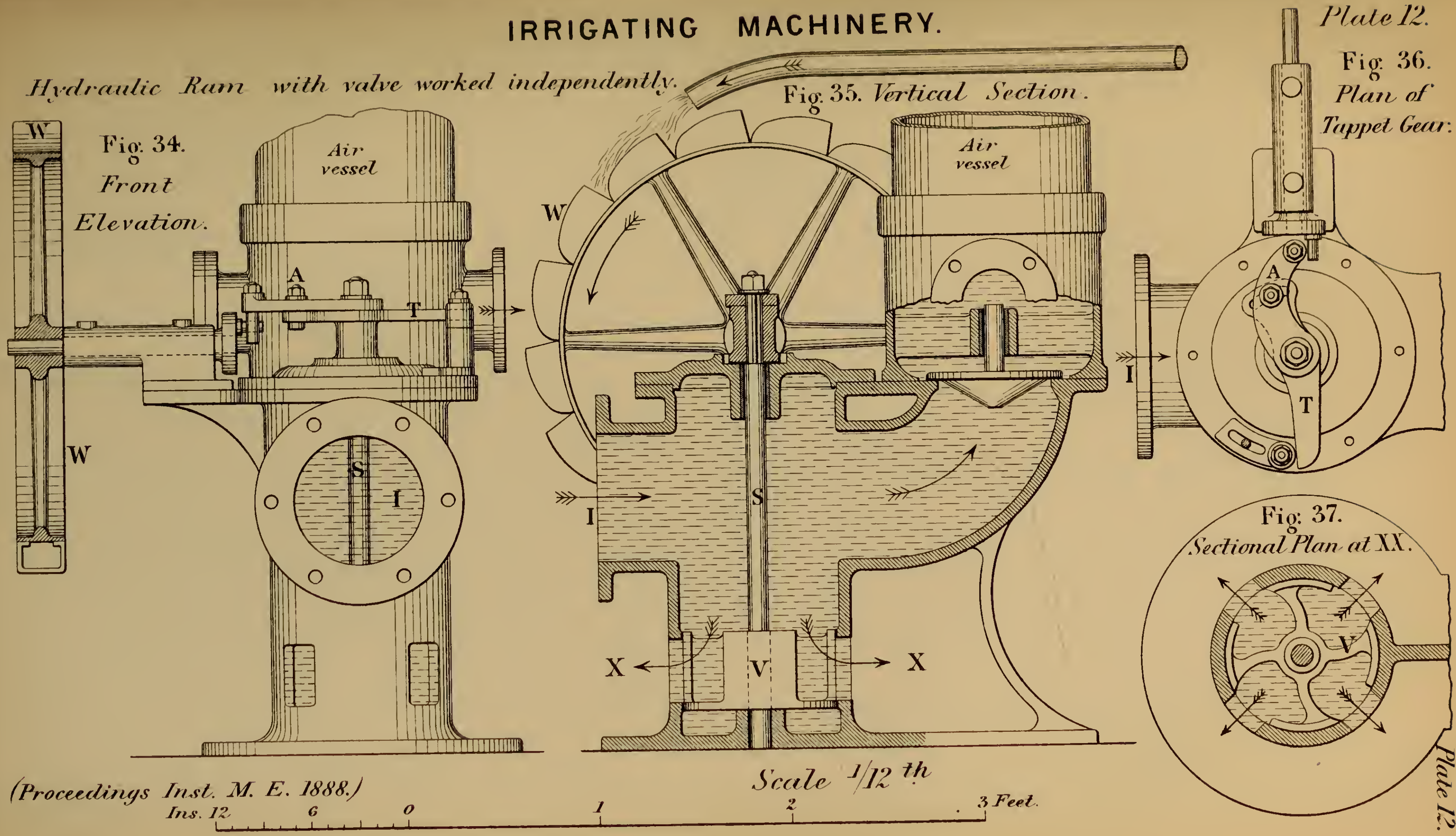


Fig. 34. Front Elevation.

Fig. 35. Vertical Section.

Fig. 36. Plan of Tappet Gear.

Fig. 37. Sectional Plan at XX.

Scale 1/12th

(Proceedings Inst. M. E. 1888.)

Plate 12.

IRRIGATING MACHINERY.

Hydraulic Footstep.

Fig. 38. Vertical Section.

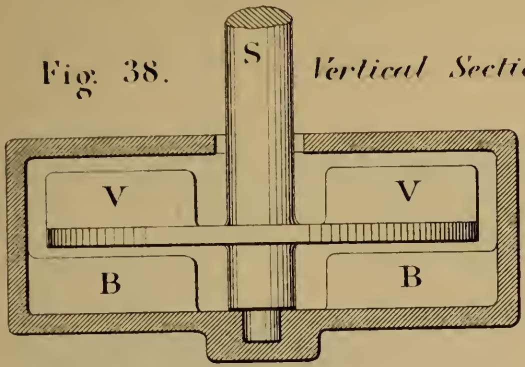
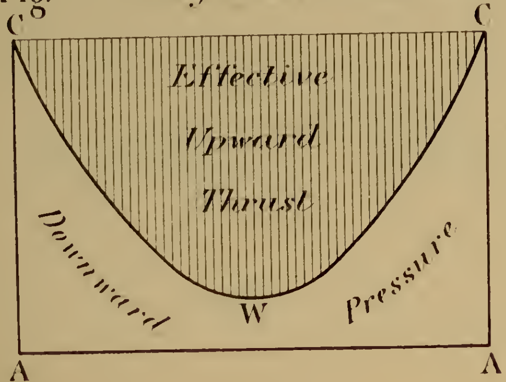
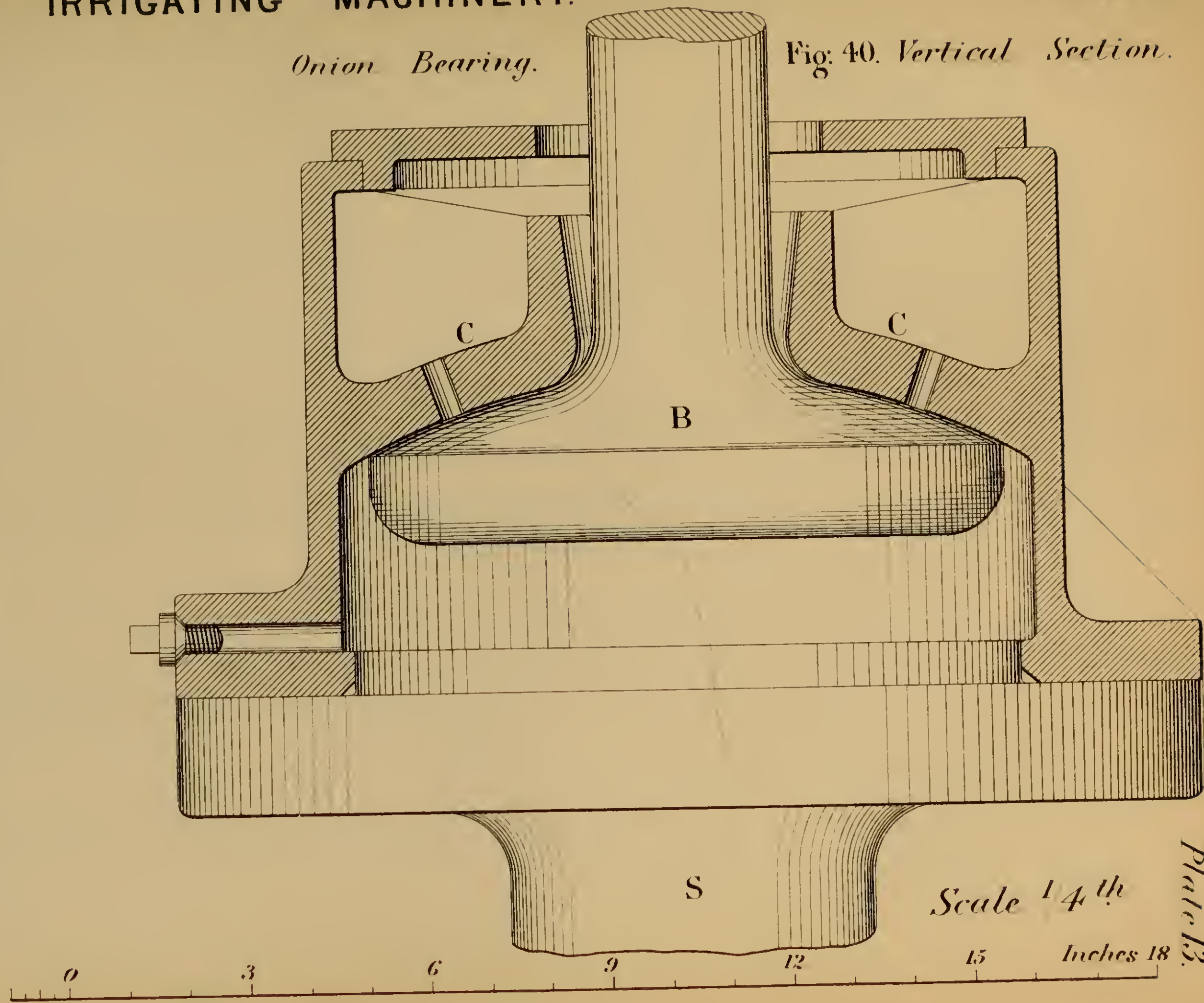


Fig. 39. Diagram of Pressures.



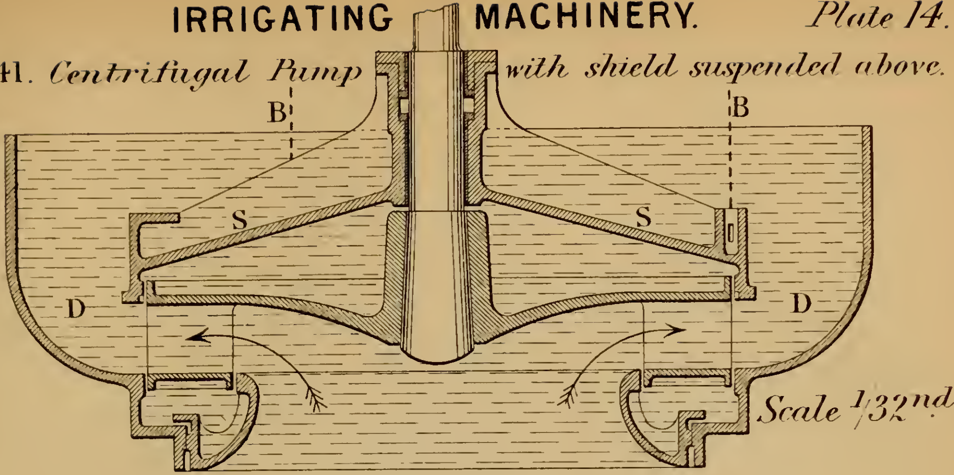
Onion Bearing.

Fig. 40. Vertical Section.



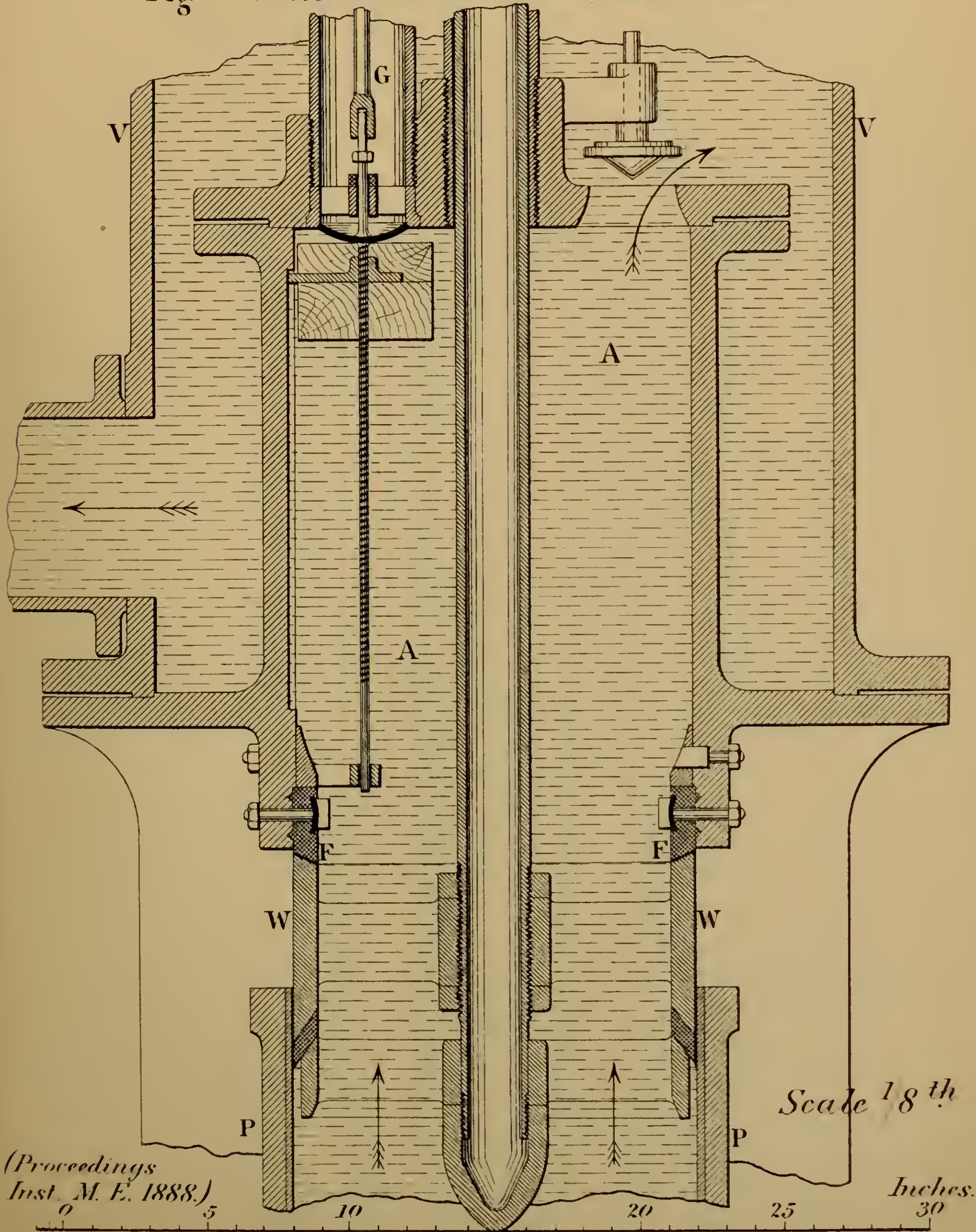
(Proceedings Inst. M. E. 1888.)

Fig. 41. *Centrifugal Pump with shield suspended above.*



Hydraulic Ram.

Fig. 42. *Ante-chamber and Waste-Valve.*



(Proceedings Inst. M. E. 1888.)

Hydraulic Ram.

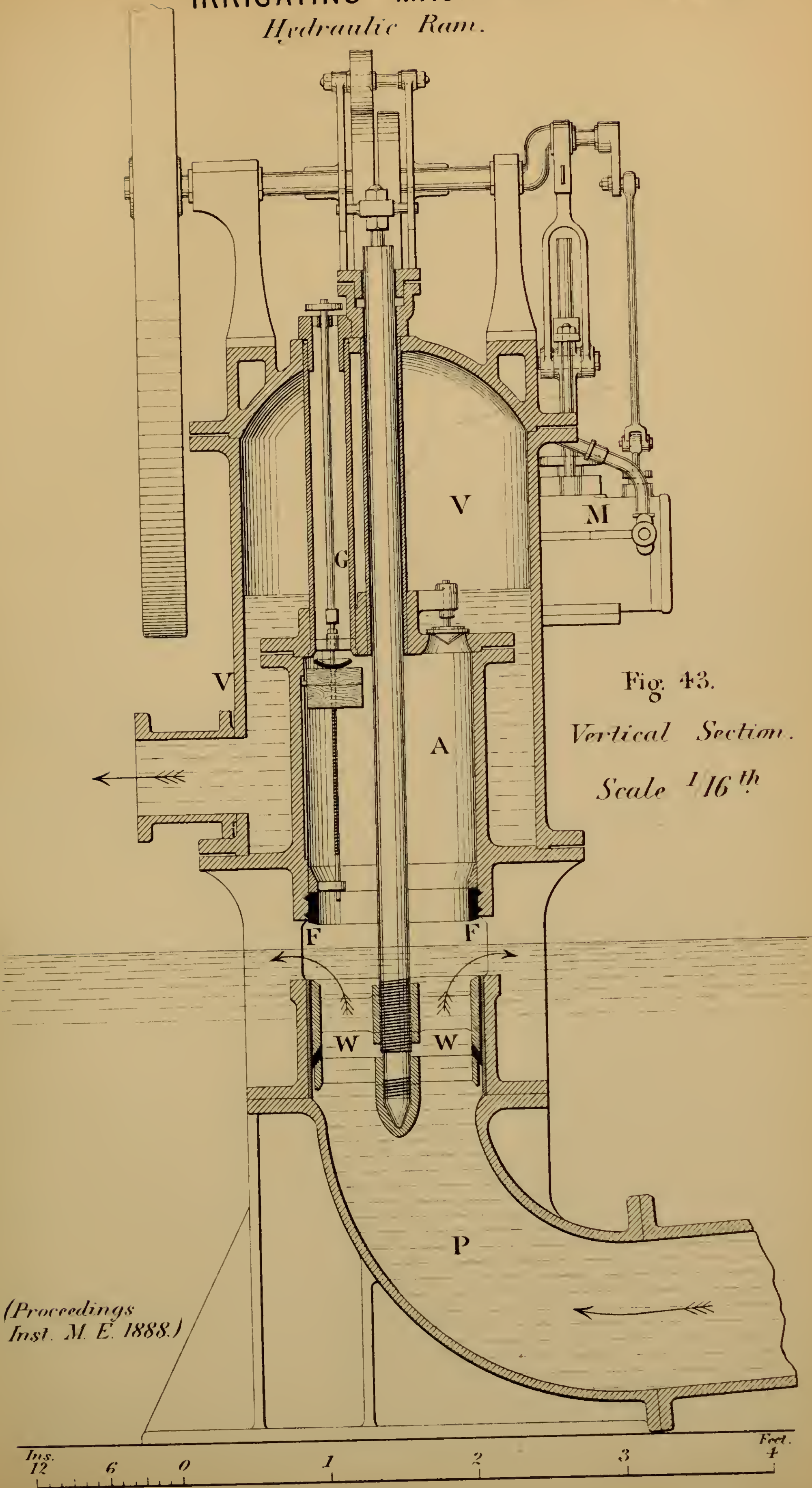


Fig. 43.

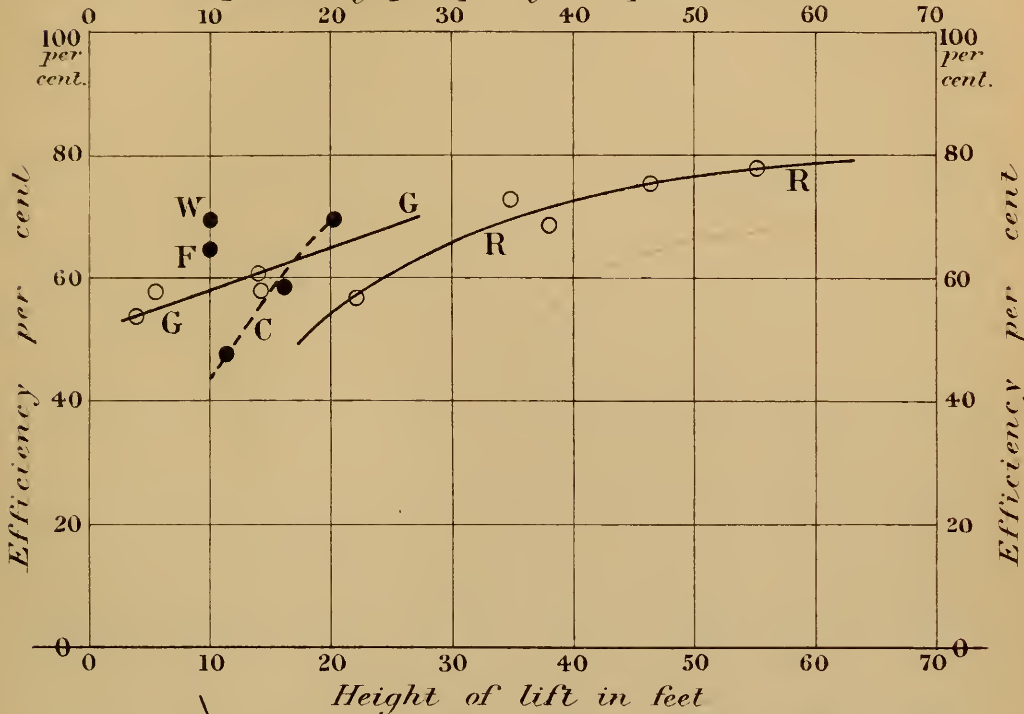
Vertical Section.

Scale 1/16th.

(Proceedings Inst. M. E. 1888.)

Fig. 44. *Efficiencies of Centrifugal and Reciprocating Pumps.*

- W ● *Scoop Wheel.*
- F ● *Centrifugal pump by Farcot & Co.*
- G ○ *Centrifugal pumps by J & H. Gwynne.*
- C ● *Centrifugal pump by Simpson & Co. at Leith Docks.*
- R ○ *Reciprocating pumps by Simpson & Co.*



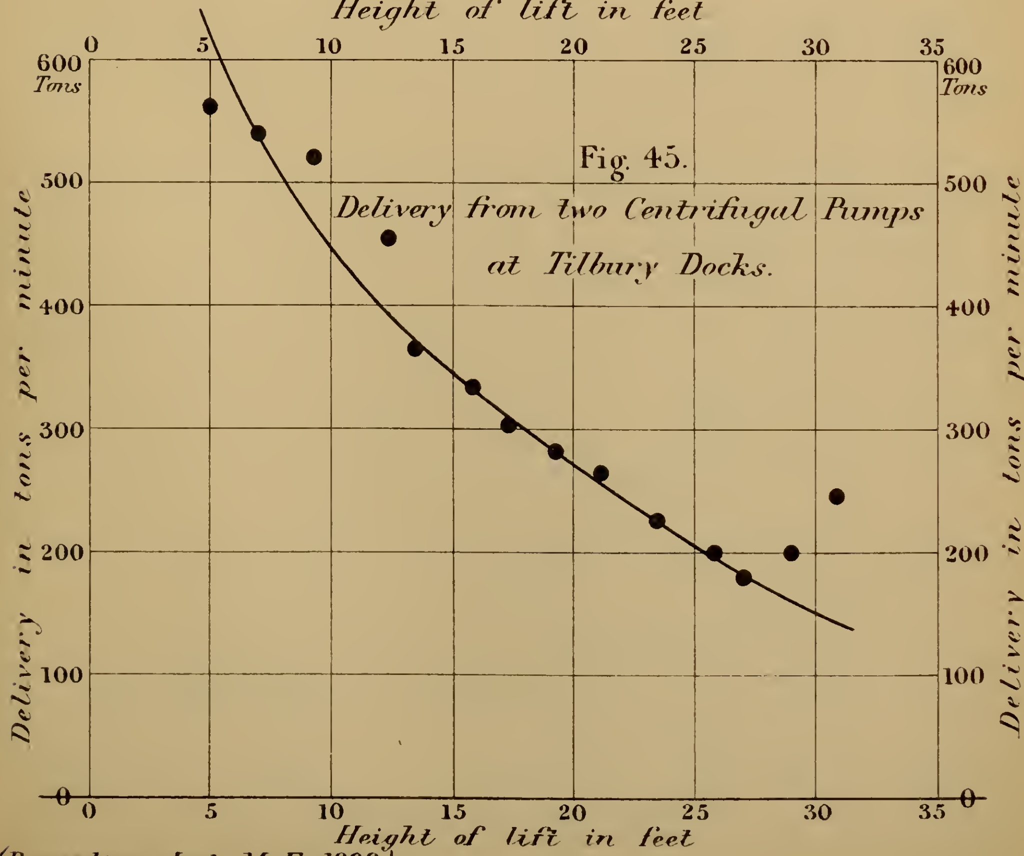
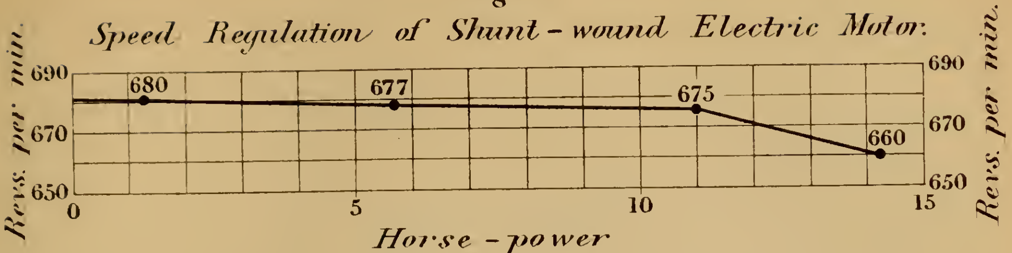


Fig. 45. *Delivery from two Centrifugal Pumps at Tilbury Docks.*

(Proceedings Inst. M. E. 1888.)

Fig: 1.

Speed Regulation of Shunt-wound Electric Motor.



INCANDESCENT ELECTRIC LIGHTING.

Fig. 2. *Duration and Cost of Lighting.*

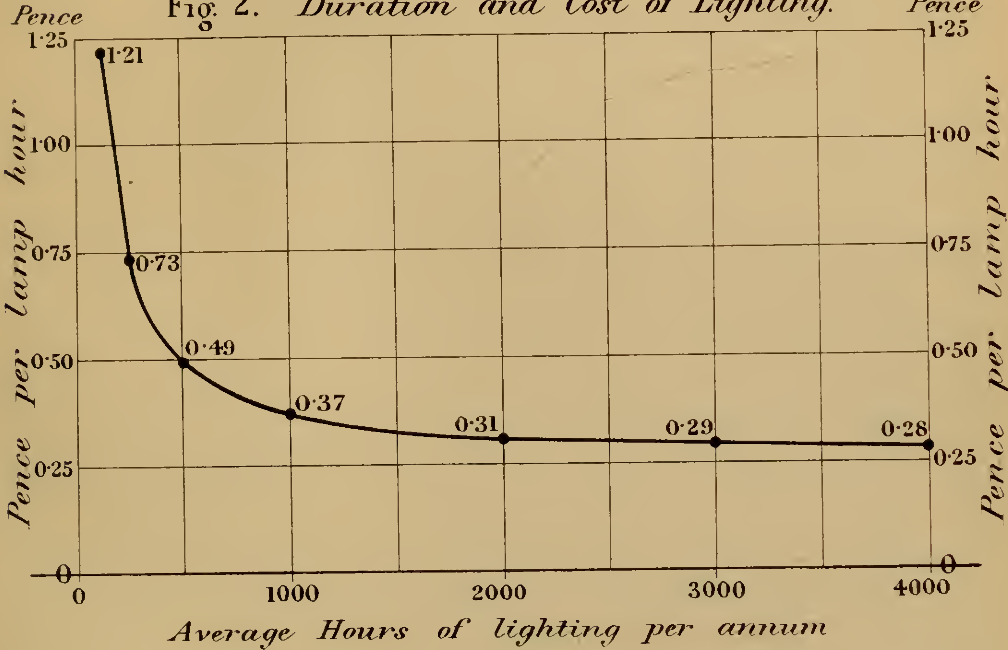
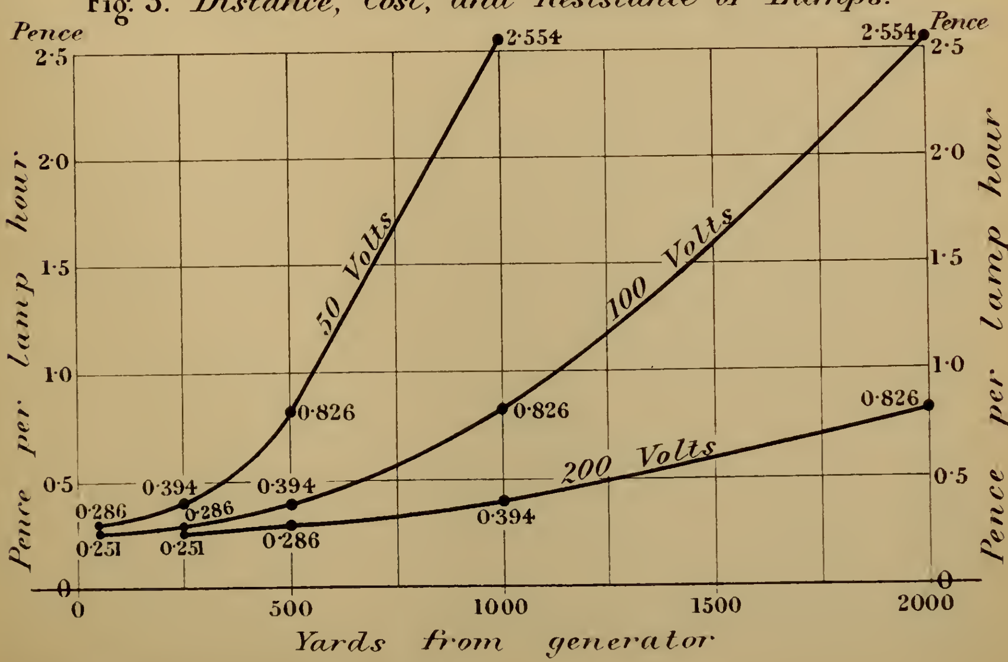


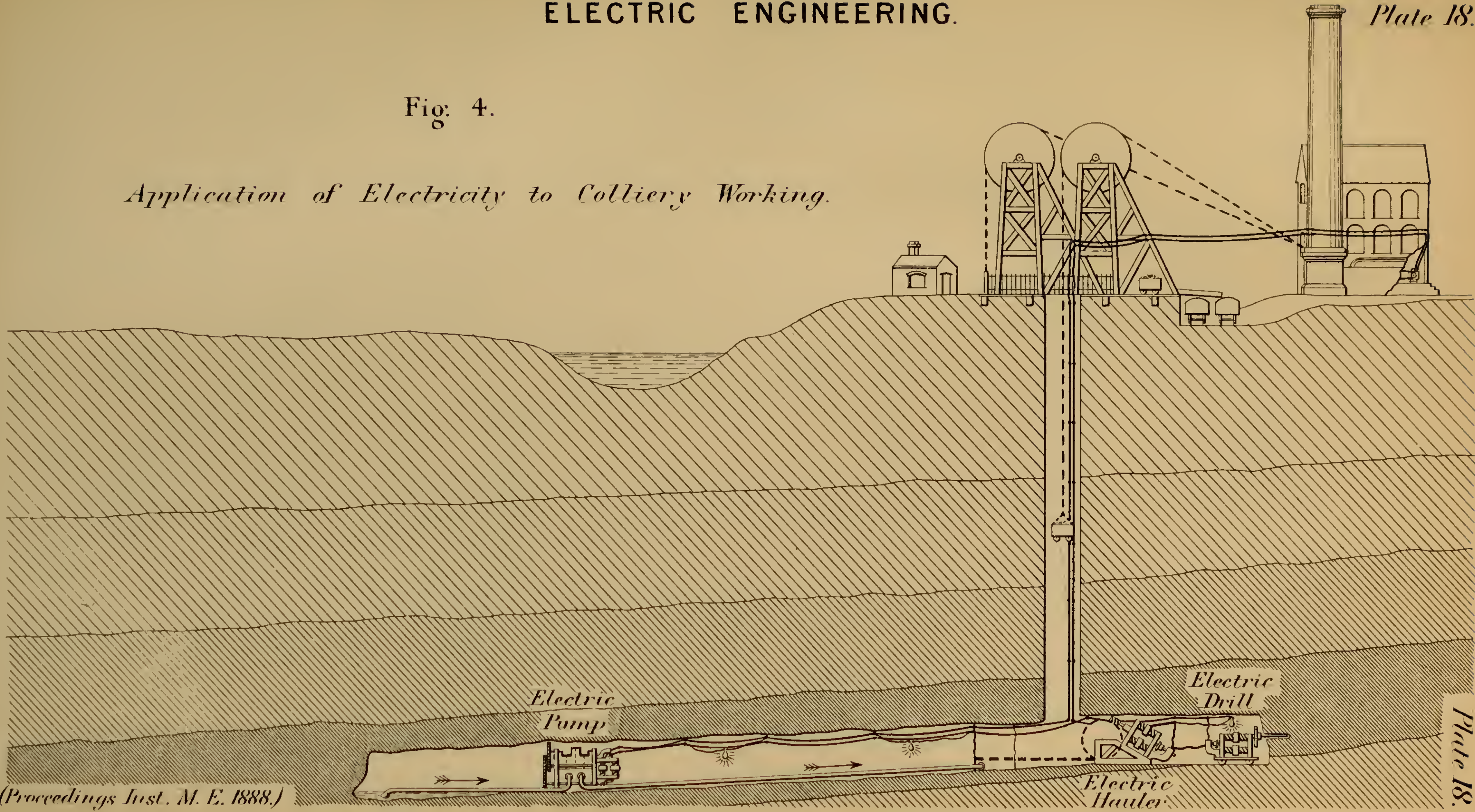
Fig. 3. *Distance, Cost, and Resistance of Lamps.*



(Proceedings Inst. M. E. 1888.)

Fig: 4.

Application of Electricity to Colliery Working.



(Proceedings Inst. M. E. 1888.)

Fig. 5. *Electric Arrangements at Hatfield.*

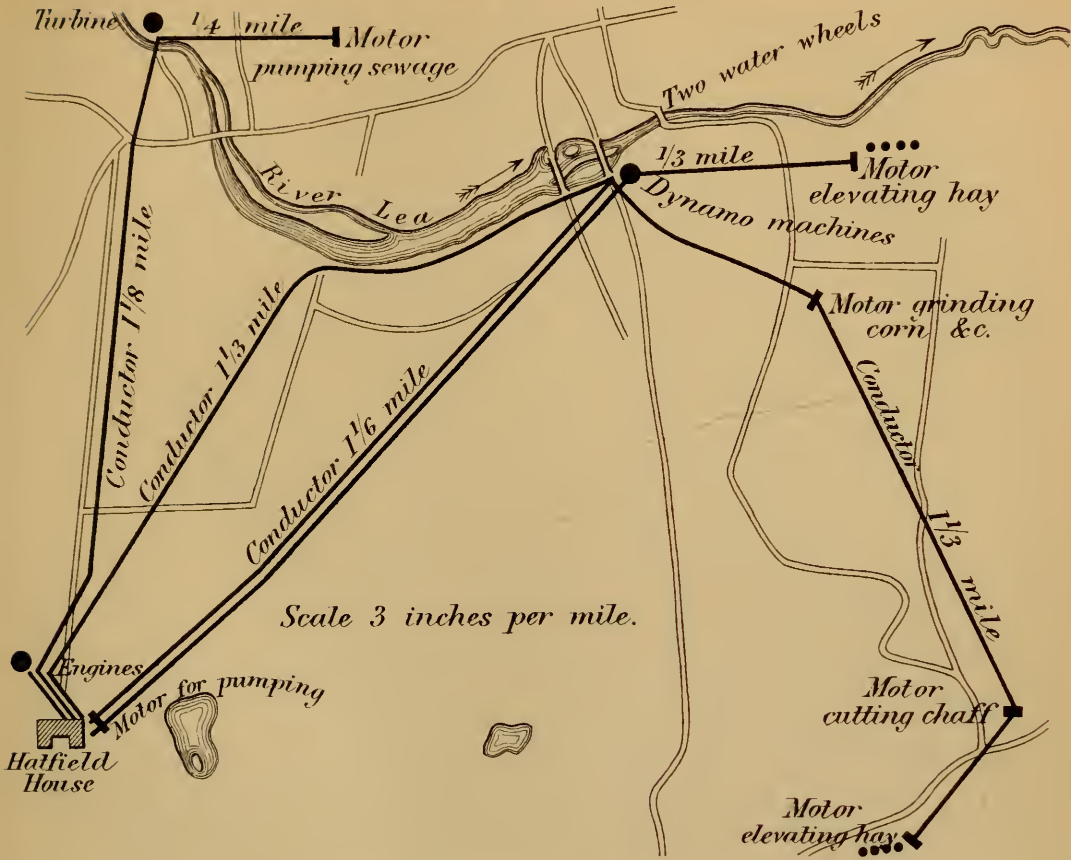


Fig. 6. *Electric Tramcar with Storage Batteries.*

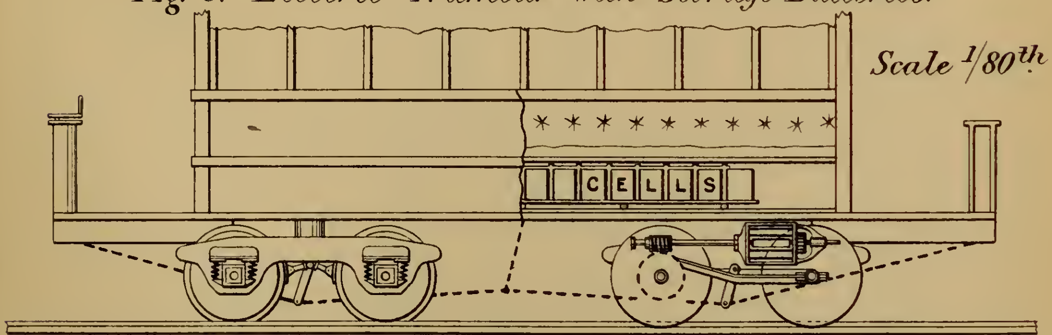
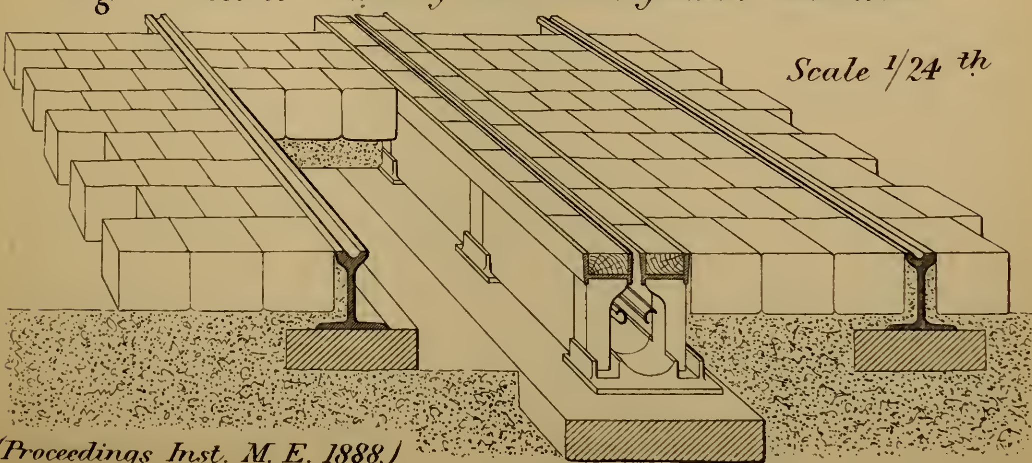


Fig. 7. *Electric Tramway with Underground Conductor.*



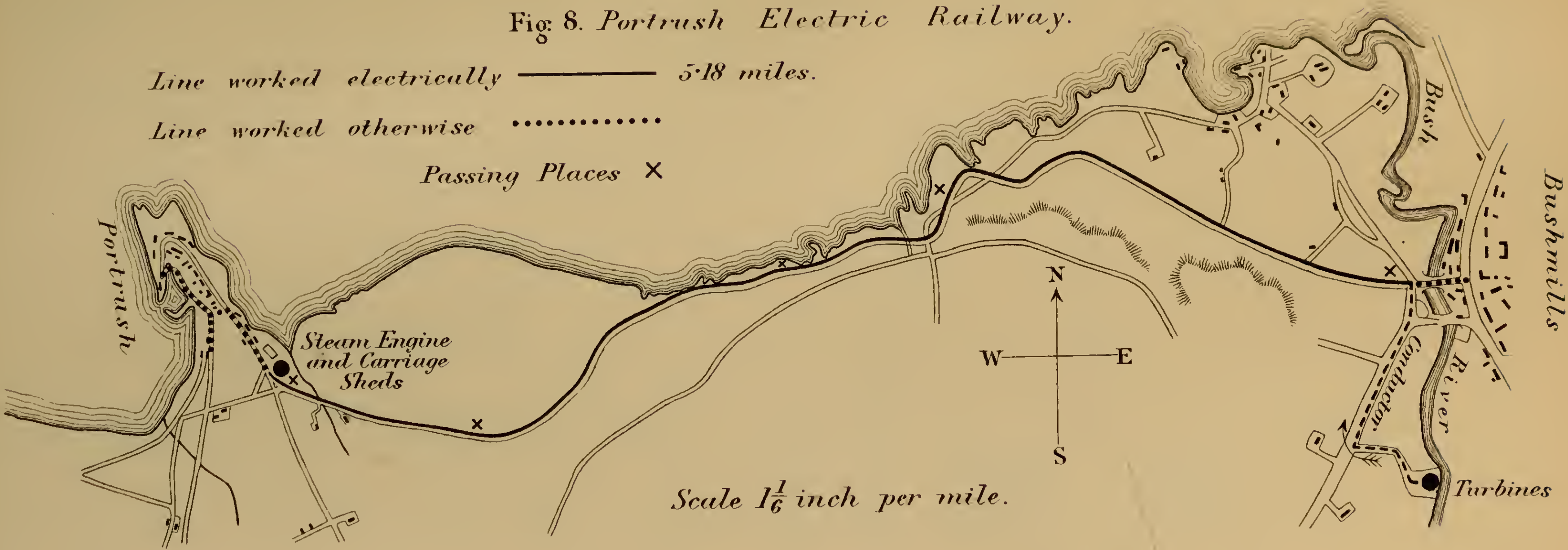
(Proceedings Inst. M. E. 1888.)

Fig: 8. *Portrush Electric Railway.*

Line worked electrically ——— *5·18 miles.*

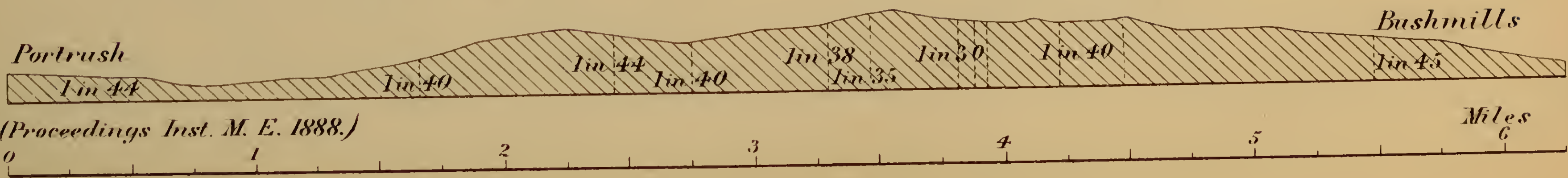
Line worked otherwise ....

Passing Places ×



Scale $1\frac{1}{6}$ inch per mile.

Fig: 9. *Profile of Line. Vertical scale, six times horizontal.*



(Proceedings Inst. M. E. 1888.)

Plate 20.

Electric Locomotive.

Scale 1/24th.

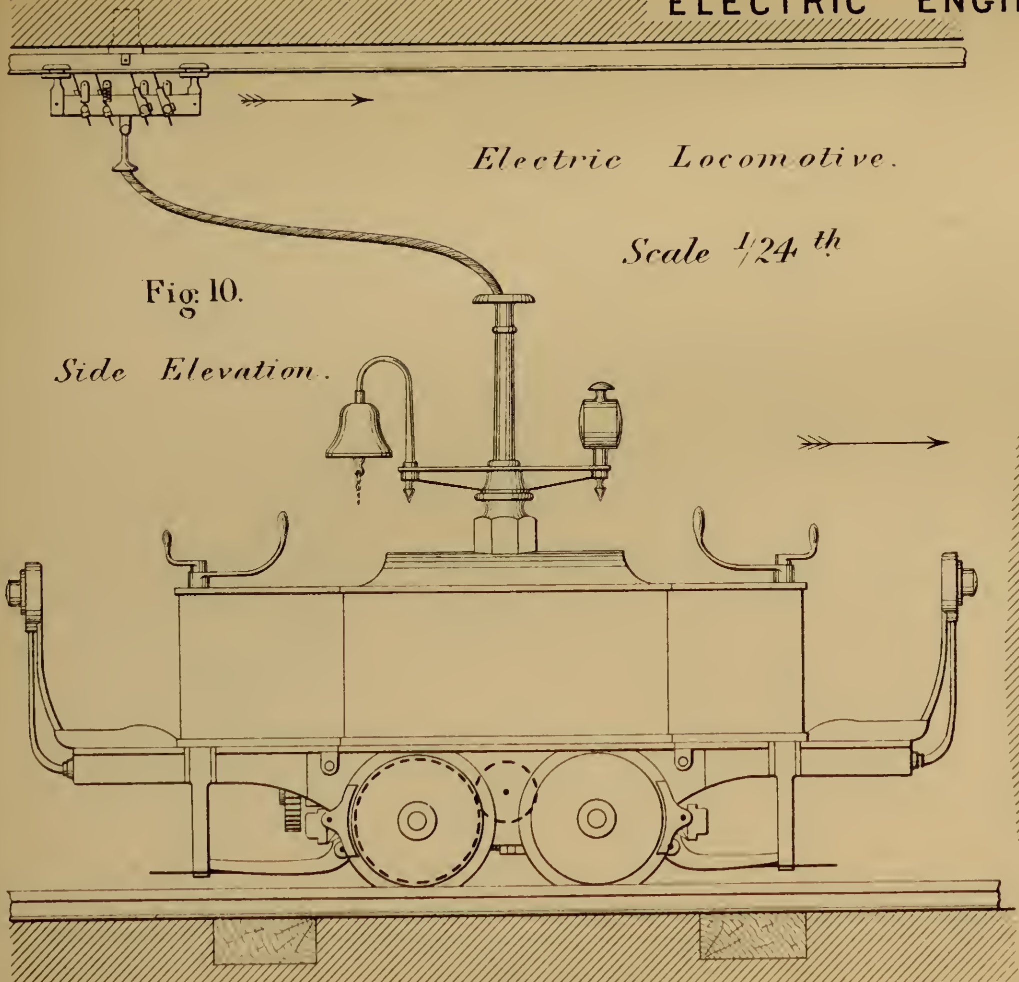


Fig. 10.

Side Elevation.

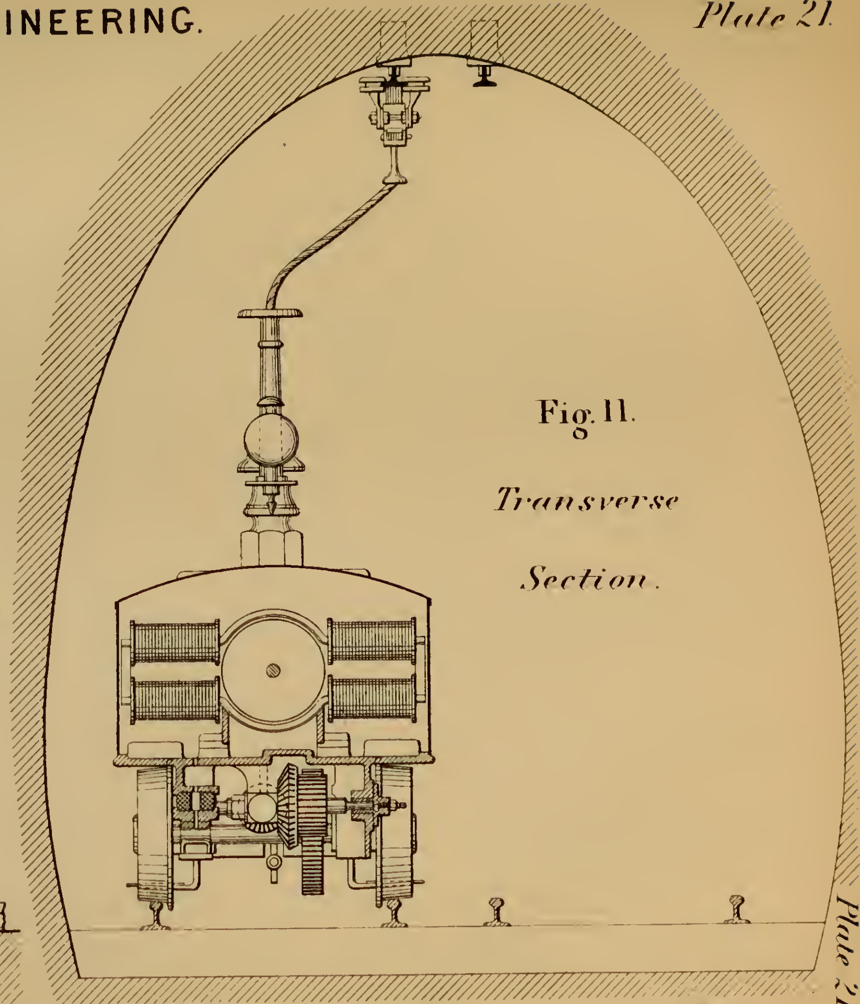


Fig. 11.

Transverse Section.

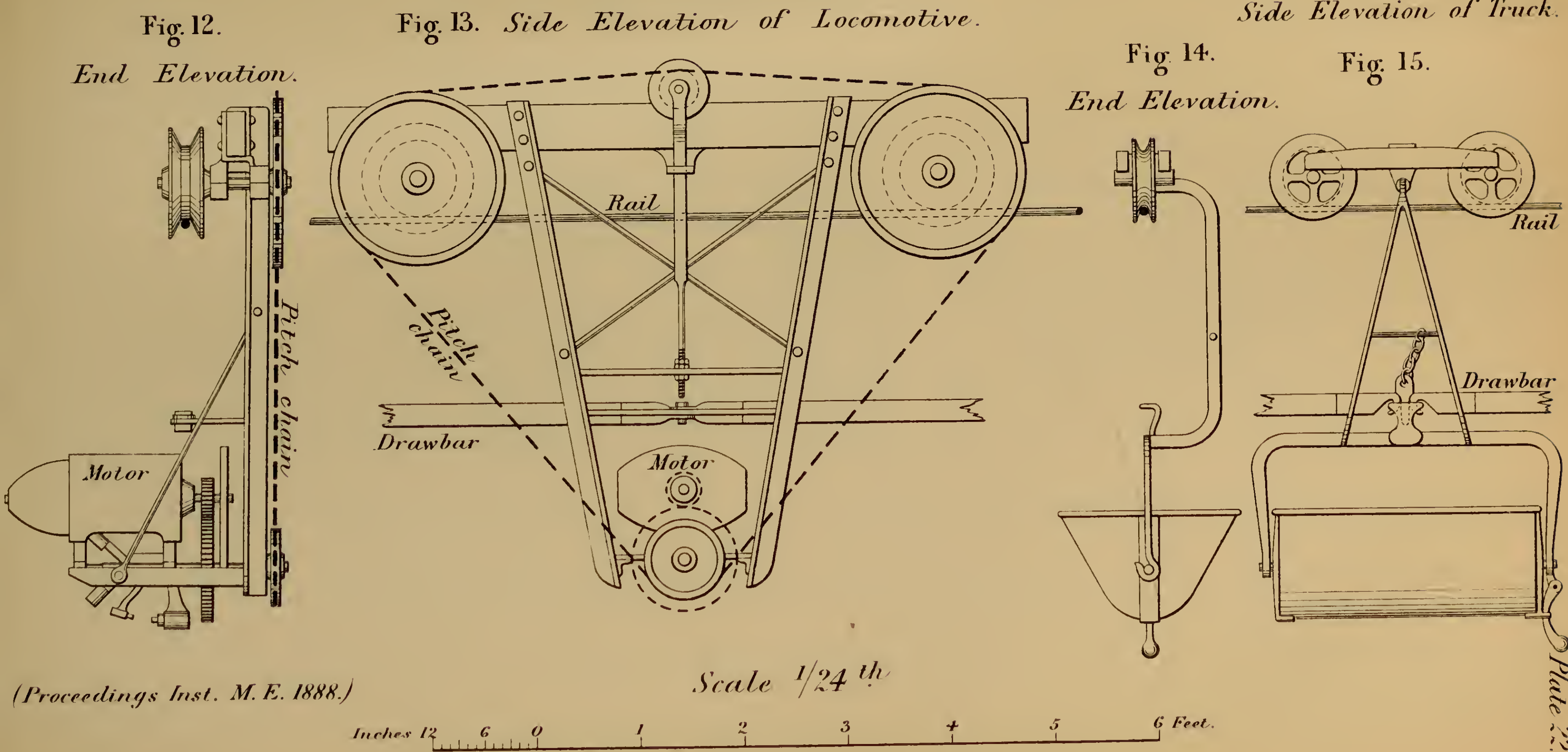
Inches 12 6 0 2 4 6 8 *Feet.*

(Proceedings Inst. M. E. 1888.)

Plate 21.

ELECTRIC ENGINEERING.

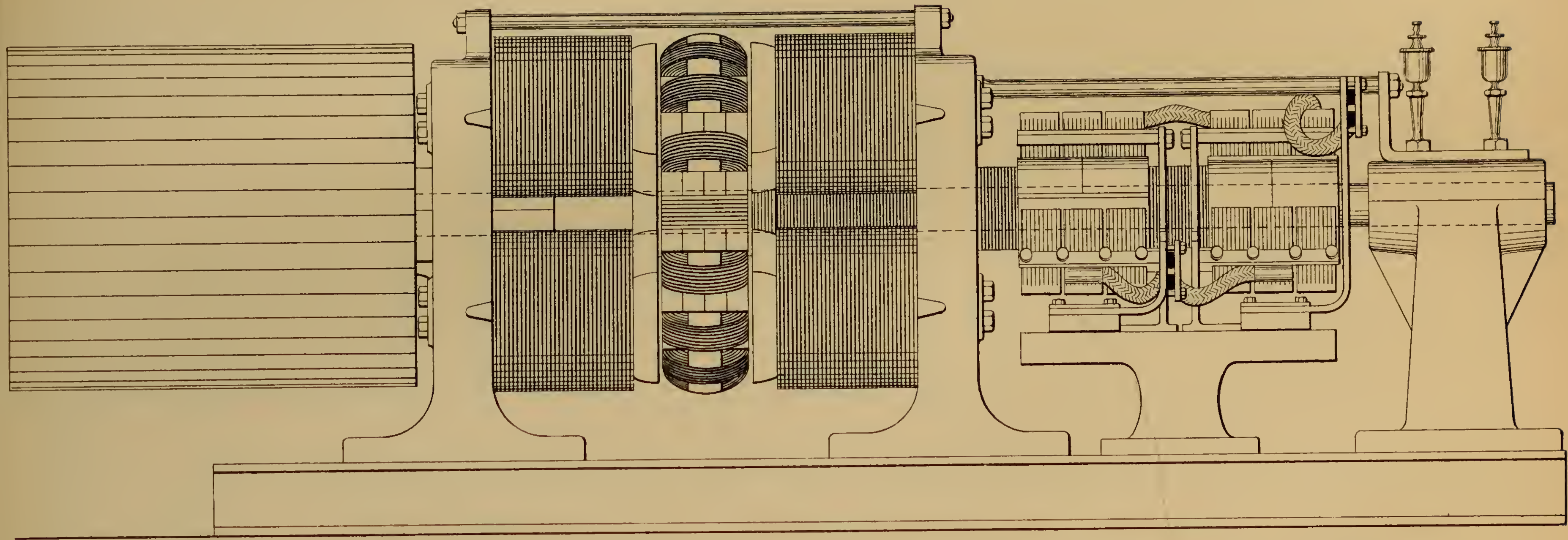
TELPHERAGE.



(Proceedings Inst. M. E. 1888.)

Plate 22.

Fig. 16. *Brush Dynamo.*



(Proceedings Inst. M. E. 1888.)

Scale 1/24 th

Inches 12 6 0 2 4 6 8 10 12 Feet.

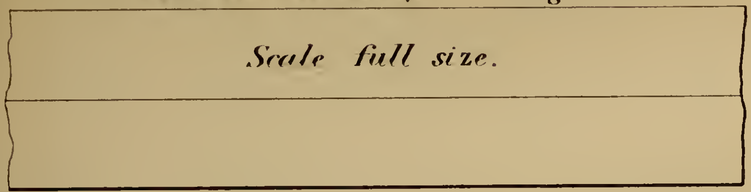
Plate 23.

ELECTRIC ENGINEERING.

Plate 24.

Electric Welding.

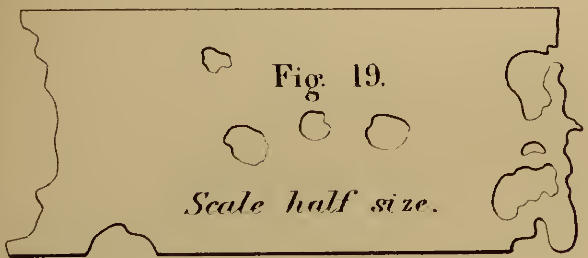
Fig. 17.



Scale full size.

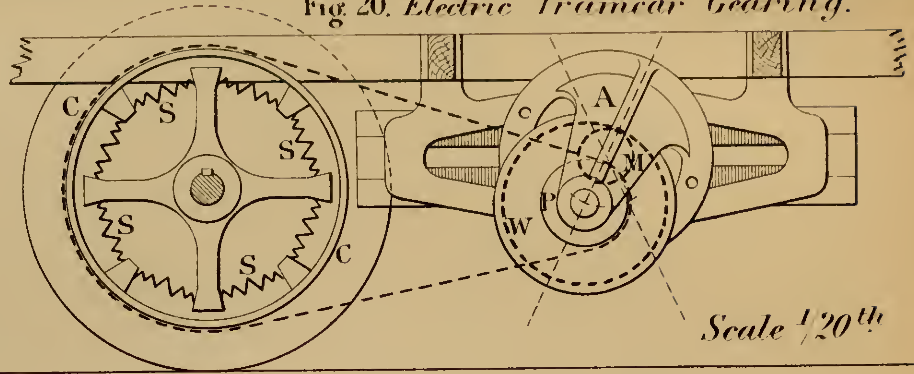
Fig. 18.

Fig. 19.



Scale half size.

Fig. 20. Electric Tramcar Gearing.



Scale 1/20th.

Electric Tramway with insulated conductor.

Fig. 21.
End Elevation.

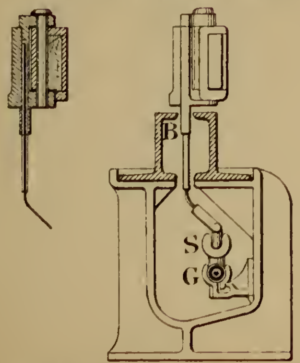
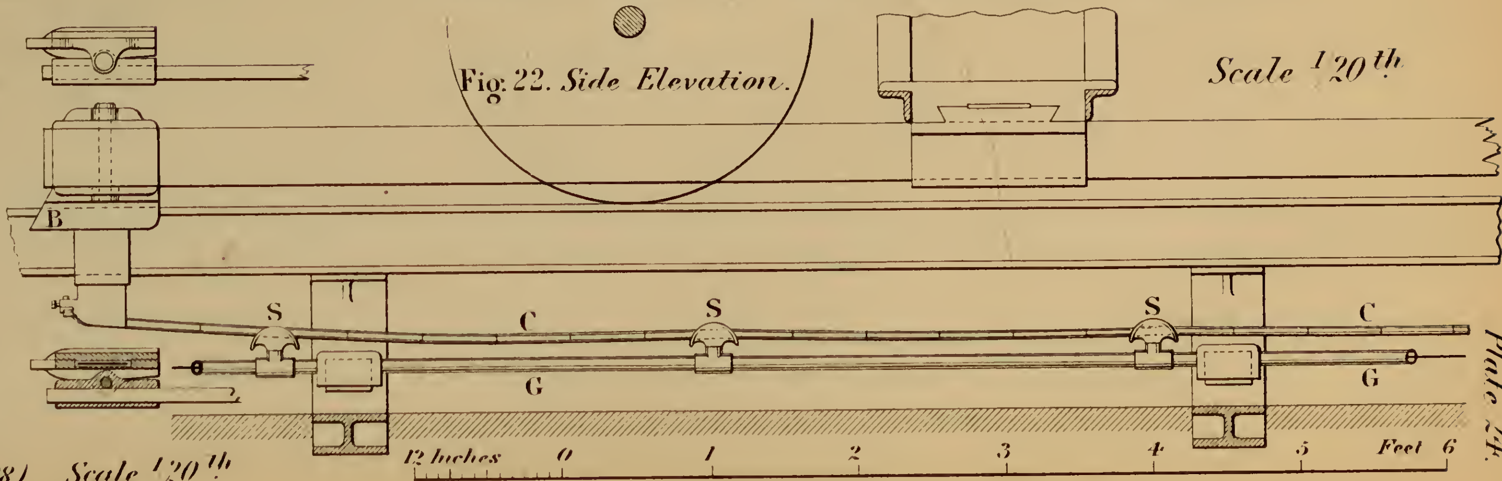


Fig. 22. Side Elevation.



Scale 1/20th.

Scale 1/20th.

(Proceedings Inst. M. E. 1888.)

Plate 24.

Institution of Mechanical Engineers.

PROCEEDINGS.

May 1888.

The Spring Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Thursday, the 3rd of May 1888, at Half-past Seven o'clock p.m.; Edward H. Carbutt, Esq., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following thirty-six candidates were found to be duly elected:—

MEMBERS.

Robert John Billinton, . . .	Derby.
Frederick Gills Brown, . . .	Brisbane.
William Brown, ...	Renfrew.
Archibald Douglas Bryce-Douglas, .	Barrow-in-Furness.
Samuel Stewart Carrick, . . .	London.
Thomas Lyon Chubb, ...	Buenos Aires.
Benjamin Colley, ...	Westbromwich.
Ezekiel Grayson Constantine, . .	Manchester.
Howard Field, ...	London.
Alfred Llewellyn Forster, . .	Newcastle-on-Tyne.
William Augustus Francken, . .	P.W.D., India.
Arthur Saunders Gore, . . .	Listowel.
Robert Abbott Hadfield, . . .	Sheffield.

Thomas Walter Harding, . . .	Leeds.
Harold Ellershaw Head, . . .	Newport, Mon.
Harry Heatly, ...	Manchester.
William Henry Jaques, Lieut. U.S.N., .	United States.
Lawrence Potter Johnson, . . .	Insein, Burma.
Albert Kapteyn, ...	London.
Arthur William Macleod, . . .	Calcutta.
Henry McLaren, ...	Leeds.
William Beswick Myers, . . .	London.
John Patrick O'Donnell, . . .	Wimbledon.
James Rowan, ...	Glasgow.
George Sellers, ...	Wakefield.
Frederick Siemens, ...	Dresden.
Werner Siemens, Ph.D., . . .	Berlin.
Sidney Straker, ...	London.
Charles James Topple, . . .	Woolwich.
James Edwardes Weyman, . . .	Guildford.
William Henry White, C.B., . .	London.
Edgar Worthington, ...	Manchester.

GRADUATES.

Wilfred Daniel Bailey, . . .	Buenos Aires.
Eric Gordon Barker, ...	Glasgow.
Herbert Pilkington, ...	Tipton.
Samuel Sugden Waddington, . .	Derby.

The President referred to the Architects' Registration Bill recently introduced in the House of Commons, which had been opposed by the Council of this Institution, of the Institution of Civil Engineers, the Surveyors' Institution, and the Royal Institute of British Architects themselves. A statement and petition against it had been drawn up for the Council by their Solicitor, Mr. Beale. The petition had been presented to the House on

Monday, 9th April, by Sir Frederick T. Mappin, Bart., M.P., Member of this Institution. The statement had been circulated to the Members of the Institution, with a request that they would support it; and many of the Members had actively and effectually done so, by writing promptly to their Members of Parliament and enlisting their interest in opposition to the bill. The consequence had been that, although the motion for the second reading of the bill came on for discussion unexpectedly, it was not even attempted to take a division on the subject, but the bill was withdrawn after an adverse debate. The Council trusted therefore that no further effort would be made to bring it in again. Meanwhile they thanked all the Members of the Institution who had so promptly responded to their appeal in support of their statement and petition, and had thus secured the withdrawal of the bill.

The petition from the Council, and their circular and statement against the bill, were as follows:—

Petition.

In Parliament, House of Commons, Session 1888.
Architects' Registration Bill.

To the Honourable the Commons of the United Kingdom of Great Britain and Ireland in Parliament assembled.

The humble Petition of the Council of the Institution of Mechanical Engineers showeth as follows:—

1. That a Bill has been introduced and is now pending in your Honourable House, intituled "A Bill to arrange for the qualification and registration of Architects, Engineers, and Surveyors," under which it is proposed to enact that all persons following the profession of (*inter alia*) Engineers shall register themselves in manner provided by the Bill, and that after the 1st day of January 1889 a qualification by examination in accordance with the provisions of the Bill shall be necessary for all persons joining the profession of Civil Engineers.

2. Your Petitioners humbly submit that the proposals of the Bill are not founded upon any public necessity, and would confer no

advantages upon the public, while they would cause great injury to the branch of the engineering profession which your petitioners represent. Although Mechanical Engineers are not expressly mentioned in the Bill, your petitioners presume that they are included within the term "Civil" as distinguished from "Military" Engineers.

3. The Institution of Mechanical Engineers was established in 1847, and had for its first President George Stephenson. It has continually increased in numbers, and now comprises more than 1,500 Members.

4. The objects of the Institution are defined in its constitution to be

(A) To promote the science and practice of Mechanical Engineering and all branches of mechanical construction, and to give an impulse to inventions likely to be useful to the Members of the Institution and to the community at large.

(B) To enable Mechanical Engineers to meet and to correspond, and to facilitate the interchange of ideas respecting improvements in the various branches of mechanical science, and the publication and communication of information on such subjects.

5. Your Petitioners humbly submit that the provisions of the Bill are as regards Mechanical Engineers actually contrary to the interests of the public and the profession. A system of qualification by examination alone is not, and cannot be, suited to such a profession as Mechanical Engineering; while to require the present Members of the Institution to register themselves as practitioners, under pain of losing the right to the title of Engineers, would be most injurious.

6. Your Petitioners respectfully submit that the system hitherto followed of depending upon the voluntary action of the engineering profession to distinguish between qualified and unqualified practitioners and to advance the progress of mechanical science has worked satisfactorily, and has caused no public inconvenience, and requires no alteration.

7. Your Petitioners therefore humbly pray that the said Bill may not be read a second time by your Honourable House.

Signed on behalf of the Council of the Institution of Mechanical Engineers,

EDWARD H. CARBUTT, *President.*

Circular.

Institution of Mechanical Engineers,
10 Victoria Chambers, London, S.W., 7th April 1888.

Architects' Registration Bill.

Dear Sir,

At the recent Meeting of the Council of this Institution, the President, Mr. Edward H. Carbutt, drew attention to the Architects' Registration Bill now before Parliament, intended to arrange for the qualification and registration of Architects, Engineers, and Surveyors; and it was resolved that a short statement should be drawn up for presentation from the Council against the second reading of the Bill. By direction of the President I have the pleasure of handing you the enclosed statement of the Council, prepared by their Solicitor, Mr. James S. Beale, for giving effect to their views.

The Council are not aware that the Bill is promoted by any persons directly interested in engineering; the names of the Members of Parliament by whom it has been prepared and brought in do not include any Member of this Institution, although there are at the present time nine Members of this Institution in the House of Commons, and several other Members of Parliament connected with engineering. It will doubtless be sufficiently gathered from the statement enclosed how serious and extensive an injury would be inflicted upon the engineering and manufacturing interests of this country if the Bill were to become law. The Council therefore trust that you will support by every means in your power their statement against the Bill, and particularly by writing at once to your borough or county Member of Parliament,

urging him to oppose the second reading of the Bill, which stands for Wednesday the 11th inst.

I am, Dear Sir, Yours truly,

ALFRED BACHE, *Secretary.*

Statement of the Council of the Institution of Mechanical Engineers against the second reading of the Architects' Registration Bill.

The Council of the Institution of Mechanical Engineers, having considered the "Bill to arrange for the qualification and registration of Architects, Engineers, and Surveyors," are of opinion that if it became law it would prove seriously detrimental to the interests of Mechanical Engineers generally, whether Members or not of this Institution, as well as to all other interests that are in any way connected with the progress of mechanical engineering science and practice.

The preamble of the Bill recites that it is expedient that persons requiring professional aid in Architecture, Civil Engineering, or Surveying, should be enabled to distinguish qualified from unqualified practitioners; and the Bill enacts a system of registration for persons now practising either of those professions, together with a future system of qualification by examination only.

The Bill deals only with Civil Engineers; but it is assumed that this description is intended to include all branches of the engineering profession, except that of Military Engineering.

The Council respectfully submit that Mechanical Engineering differs widely, as regards both education and qualification, from the other divisions of the profession; that the Bill is not founded upon any public requirement; and that a system of compulsory registration and examination for Mechanical Engineers would be injurious to the interests of mechanical science.

The Institution of Mechanical Engineers was established in 1847, and had for its first President George Stephenson, who was succeeded by his son Robert, Sir William Fairbairn, Bart., Sir Joseph Whitworth, Bart., John Penn, James Kennedy, Robert

Napier, Sir William Siemens, and other eminent Mechanical Engineers still living. Most of these rose from the ranks, to achieve by their own force of character a world-wide reputation as Mechanical Engineers; and would have been debarred from so rising, had they been hampered at the outset of their career by the restrictive requirements contemplated in the Bill.

The Institution, of which Mr. Edward H. Carbutt, lately a Member of your Honourable House, is the President, now numbers over 1,500 Members, whose qualifications for membership have been approved by the Council previously to their names being included in the ballot lists for their election. A large number of the Members have, like many of the Presidents of the Institution, risen to their present position from circumstances under which the system of examination and registration proposed by the Bill would have put an early stop to their career.

The science of Mechanical Engineering is closely connected with every manufacturing industry in the country. A large number of the Members of the Institution of Mechanical Engineers are directly engaged in manufactures; and the large works throughout the country are continually attracting to their service men educated and fully qualified as Mechanical Engineers. All these now retain the title of Engineers, and through their connection with the Institution of Mechanical Engineers contribute materially to the progress of mechanical science. The Bill would compel them to register as practitioners, under pain of losing their professional status or becoming subject to penalties. The Council respectfully submit that this would be equally impolitic and unjust.

On account of these and other objectionable features of the Bill, the Council of the Institution of Mechanical Engineers trust that it may not receive the sanction of Parliament.

The PRESIDENT called the attention of the Members to the Paris Universal Exhibition to be held next year. As President of the Institution he had already been taking an active part in getting up a committee in this country to look after the interests of English exhibitors. At the last Paris Exhibition in 1878 the government of this country had spent a great deal of money—something like £67,000—in encouraging English contributors to go there and in looking after them; but this time they were not going to spend anything. The Council thought it a great pity that English engineers should not be properly represented in Paris, because they were strongly under the impression that they must look to their laurels, and that, if they did not keep on striving, others would come and occupy the front position they had hitherto held. New countries were opening up, such as South America; and no doubt many people would come over from South America to the Paris Exhibition, and if English engineers were not properly represented there they would lose a large amount of trade with that and other countries. This being his own feeling, when M. Berger, the Director-General of the Paris Exhibition, came to London recently, he met him and discussed the matter; and an Executive Committee had now been formed under the chairmanship of the Lord Mayor and the vice-chairmanship of Lord Brassey, on which the Institution was represented by Sir Lowthian Bell, Bart., Past-President, Sir Bernhard Samuelson, Bart., M.P., Sir Andrew Fairbairn, Sir Douglas Galton, member of Council, Sir William T. Lewis, Mr. George B. Bruce, Mr. Henry Chapman, Mr. James Dredge, Mr. Henry D. Marshall, and himself. His reason for calling the attention of the Members to this matter was that the sooner they applied for space the better, because there was very little space at the disposal of the English exhibitors, and it was most desirable they should make the best show that could be made. He trusted therefore they would not only be exhibitors themselves, but also persuade their friends to exhibit, so that they might have a proper exhibition, and one worthy of England and of this Institution.

The following Papers were then read and discussed:—

Third Report of the Research Committee on Friction: Experiments on the Friction of a Collar Bearing.

Description of Emery's Testing Machine; by Mr. Henry R. Towne, of Stamford, Connecticut, U.S.A.

Shortly after Ten o'clock the Discussion was adjourned till the following afternoon. The attendance was 79 Members and 49 Visitors.

The Adjourned Meeting was held at the Institution of Civil Engineers, London, on Friday, the 4th of May 1888, at Half-past Two o'clock p.m.; Edward H. Carbutt, Esq., President, in the chair.

The Discussion took place on Mr. Towne's Paper on Emery's Testing Machine, read on the previous evening. As it was understood that the Testing Machine itself was expected to be on view in London at an early date, the discussion was not finally closed, but was left open for additional remarks at a future Meeting from Members who might meanwhile have taken advantage of the opportunity thus to be afforded them for inspecting the machine in operation.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers for their kindness in granting the use of their rooms for the Meeting of this Institution.

The Meeting then terminated, shortly after Four o'clock. The attendance was 54 Members and 23 Visitors.

In the evening the Annual Dinner of the Institution was held at the Criterion, Piccadilly, the President occupying the chair, and was largely attended by the Members and their friends. The Dinner was honoured by the presence of the Right Honourable the Marquis of Hartington, M.P., President of the National Association for the Promotion of Technical Education; and the following Guests also accepted the invitations sent to them:—the Right Honourable Lord Ashbourne, Lord Chancellor of Ireland; Captain Lord Charles Beresford, R.N., C.B., M.P.; the Right Honourable H. C. Raikes, M.P., Postmaster-General; the Right Honourable Sir Ughtred J. Kay-Shuttleworth, Bart., M.P.; the Right Honourable A. J. Mundella, M.P.; Sir James P. Corry, Bart., M.P.; Sir Edward J. Harland, Bart.; Sir Edward W. Watkin, Bart., M.P., Chairman of the South Eastern Railway; Sir Donald Currie, K.C.M.G., M.P., Managing Director of the Castle Mail Packets Co.; Sir Rawson W. Rawson, K.C.M.G., C.B.; Sir Juland Danvers, K.C.S.I., Public Works Department, India Office; Sir Frederick A. Abel, C.B., F.R.S., Chemist to the War Department; Sir Vincent Kennett-Barrington; Sir Owen Roberts, Clerk to the Clothworkers' Company; Sir Henry E. Roscoe, M.P., F.R.S., Secretary of the National Association for the Promotion of Technical Education; Colonel Duncan, C.B., M.P.; Mr. Thomas Gray, C.B., Assistant Secretary, Board of Trade; Mr. William J. Beadel, M.P., President of the Surveyors' Institution; Mr. Edward S. W. de Cobain, M.P.; Mr. Arthur B. Forwood, M.P., Secretary to the Admiralty; Mr. Alfred Giles, M.P.; Mr. Frank Lockwood, Q.C., M.P.; Colonel Makins, M.P., Chairman of the Gas Light and Coke Company; Professor G. G. Stokes, M.P., F.R.S., President of the Royal Society; Mr. Thomas Sutherland, M.P., Chairman of the Peninsular and Oriental Steam Navigation Company; Captain J. Sydney Webb, Deputy Master, Trinity House; Commander F. E. Chadwick, United States Legation; Mr. George B. Bruce, President of the Institution of Civil Engineers; Mr. William Crookes, F.R.S., President of the Chemical Society; Mr. Edward Graves, President of the Society of Telegraph Engineers; Mr. John Collett, Director of Contracts, Admiralty; Dr. Robert Giffen, Assistant Secretary, Board of Trade; Mr. E. C. Nepean, Director of Contracts, War Office; Professor W.

Chandler Roberts-Austen, F.R.S., Chemist and Assayer, Royal Mint; Mr. John Benson; Mr. George Findlay, General Manager of the London and North Western Railway; Mr. James Forrest, Secretary of the Institution of Civil Engineers; Mr. Frederick Hendriks, Royal Statistical Society; Mr. George Holmes, Secretary of the Institution of Naval Architects; Mr. J. S. Jeans, Secretary of the Iron and Steel Institute; Mr. Robert A. McLean, Auditor; Mr. H. L. Millar, Treasurer; Mr. Kenric B. Murray, Secretary of the London Chamber of Commerce; Mr. Henry Nelson; Mr. Henry Oakley, General Manager of the Great Northern Railway; Mr. John Rhodes; Major Fairfax Rhodes; Mr. Julian C. Rogers, Secretary of the Surveyors' Institution; Mr. Leasowe Walker, Mayor of Scarborough; and Mr. H. Trueman Wood, Secretary of the Society of Arts.

The President was supported by the following Officers of the Institution:—the Right Honourable Lord Armstrong, C.B., F.R.S., and Sir Lowthian Bell, Bart., F.R.S., Past-Presidents; Mr. Daniel Adamson, Mr. David Greig, Mr. Arthur Paget, and Mr. Joseph Tomlinson, Vice-Presidents; Mr. William Anderson, Sir James N. Douglass, F.R.S., Sir Douglas Galton, K.C.B., F.R.S., Mr. Edward B. Marten (Stourbridge), Mr. Benjamin Walker, and Mr. J. Hartley Wicksteed, Members of Council.

After the usual loyal toasts, the President proposed "Our Guest," which was acknowledged by the Right Honourable the Marquis of Hartington, M.P., President of the National Association for the Promotion of Technical Education. The toast of "The Houses of Parliament," proposed by Mr. Daniel Adamson, Vice-President, was acknowledged on behalf of the House of Lords by the Right Honourable Lord Ashbourne, Lord Chancellor of Ireland, and the Right Honourable Lord Armstrong, C.B., F.R.S., Past-President; and for the House of Commons by Sir James P. Corry, Bart., M.P. The Right Honourable Lord Stalbridge proposed the toast of "The Army and Navy," which was acknowledged by Colonel Duncan, C.B., M.P., and Captain Lord Charles Beresford, R.N., C.B., M.P. The concluding toast of "The Institution of Mechanical Engineers," proposed by the Right Honourable Sir Ughtred J. Kay-Shuttleworth, Bart., M.P., was acknowledged by the President.

The Right Honourable the Marquis of Hartington, M.P., in responding to the toast of his health as President of the National Association for the Promotion of Technical Education, said it was a great deal easier to conceive and to feel how extensive had been the work performed in recent years by mechanical engineers than to define its extent clearly. It was only fifty years since the first successful voyages across the Atlantic were made by steamships from Bristol and Liverpool; while voyages could now be made with largely increased speed and comfort to the antipodes and all round the world. Perhaps scarcely thought enough was given to the amount of labour and scientific study and intellectual effort which had been expended by mechanical engineers in bringing to their present state of perfection the steamships and engines whereby these extraordinary feats had been achieved. There were also innumerable advantages and conveniences resulting from the perfection to which the system of railway and telegraphic communication had now been brought; and these he feared too seldom elicited even a passing tribute to those who had been amongst the greatest benefactors of our race. Perhaps the most interesting subject to which he could refer on the present occasion was the part taken by the mechanical engineers of this country in the maintenance and extension of our material and industrial supremacy, and the conditions upon which that supremacy depended. We had no doubt great material resources; but not greater than were possessed by many other countries. We had an industrious and intelligent population; but not more industrious and intelligent, and perhaps less economical and thrifty, than the populations of other countries with which we were in competition. It was also the fact that up to the present time other countries had been making greater efforts than we had yet made to give a practical turn to the national instruction of their people, and to prepare them more directly for the competition prevailing everywhere in industrial pursuits. It was true that, owing to the thrifty character of our industrial and commercial classes, we possessed vast stores of accumulated capital; but these would not suffice to maintain the pre-eminence of our industrial position, were it not for the daily

labour of mechanical engineers, who took note of every fresh scientific discovery, and used it for the purpose of increasing the productiveness and economy of labour, and the excellence and cheapness of production. A great deal had been heard recently about depression of trade; but if it were not for the labours of mechanical engineers, he believed it would not be merely depression of trade that would have to be lamented, but something more nearly approaching suppression and extinction of trade. While himself taking a warm interest in the promotion of technical education, he did not profess to be an authority on the subject; and all he could do was to endeavour to arouse as much interest as he could in it, and to induce the unscientific public to join him in paying attention to the advice of those who were authorities in the matter. He had been greatly struck by the fact that, in every country in Europe which competed with England in industrial or commercial pursuits, greater attention had recently been paid to giving a practical direction to the education of the people than we had hitherto considered it necessary to pay. Although we had established a national and tolerably complete system of popular instruction, other countries earlier than ourselves had been impressed with the importance of making their national instruction not only literary, but also practical, technical, and commercial; and in this respect he could not but think they had gained some considerable advantages over ourselves. There was no occasion however for taking a desponding view of our position; for he had great confidence in the energy, the skill, and the intelligence of our people. Nevertheless he believed those were facts which it would be madness on our part to ignore. If a new process or a new invention, greatly superior to what was practised here, were discovered in any other country, we should consider it necessary either to adopt it, or if possible to improve upon it; otherwise we must resign ourselves to be defeated in the competition connected therewith. If it were true, as he believed it was, that the system of national education in other countries was being carried on so as to make manual labour more intelligent and more skilled and therefore more valuable, this was a fact which was just as important, and had consequences of exactly

(The Marquis of Hartington.)

the same character, as if a foreign nation were to discover a new process or invention. There could be no doubt that foreign countries had not merely made the attempt, but had succeeded to a very considerable extent in giving a more practical turn to the education of their people in all branches of industry and commerce where science and art could be usefully and successfully applied. We had thus fallen behind in this department of our own national instruction; and it seemed to him that it would be worse than idle —it would be criminal—if we were for a moment to ignore the consequences which might hence result, not only to our present commercial and manufacturing position in the world, but to our future industrial prosperity. He need scarcely assure mechanical engineers of his own interest in the maintenance and prosperity of everything which pertained to the engineering pre-eminence of this country.

THIRD REPORT OF THE RESEARCH COMMITTEE ON FRICTION.

Experiments on the Friction of a Collar Bearing.

Description of the Apparatus.—As shown in Plates 25 to 27, the machine with which these experiments were tried consisted of a steel ring R, Figs. 4 and 5, of rectangular section, which was pressed between two cast-iron discs C D. The annular bearing surfaces of the discs were covered with gun-metal, and were 12 inches inside diameter and 14 inches outside, giving on each disc an area of exactly 40 square inches, after deducting the oil channels. The pressure was applied by a large spiral steel spring S, one end of which abutted against the front disc D, while the other end pressed against a nut N on a central bolt B connected with the back disc C. Screwing up the nut N compressed the spring S, and tended to pull the two discs together, causing them to press the ring R between them. The bolt B was connected with the back disc C by a ball-and-socket joint, so as to ensure the pressure being distributed uniformly all round the ring. The back disc C was keyed on the end of a horizontal rotating shaft H, and drove the front disc D by means of four feathers engaging in four notches, in such a way that the front disc D, though compelled to rotate with its fellow C, was free to move in any other way relatively to it. The two discs rotating together, and pressing on the steel ring R, tended by friction to carry it with them, but were prevented from doing so by a horizontal lever L, Fig. 5, attached to the ring. The holding force on the end of the lever being measured by a spring-balance showed the amount of the friction between the ring and the discs. The ring was held concentric with the discs by resting on two friction-wheels W, Figs. 3 and 5, because any shoulder on the discs for this purpose was inadmissible as introducing another kind of friction.

For First and Second Reports see Proceedings 1883, page 632; and 1885, page 58.

The overhanging weight of the spring S and bolt B, which would have tended to relieve the pressure on the top of the ring R and increase it on the bottom, was taken off by a counterbalance weight, on the end of a rope that passed over two pulleys and was attached to a brass collar, Fig. 1, in which the end of the bolt B ran as in a bearing. This arrangement, while carrying the overhanging weight of the spring and bolt, allowed them to run a little out of truth if the spring required it.

The true measurement of the length of the spring S, for the purpose of ascertaining the pressure exerted by it, was a point which required special attention. The bolt B had a hole drilled up its centre, along which passed a freely fitting measuring rod M, Fig. 4, Plate 26. The outer end of this measuring rod was flush or nearly so with the end of the bolt; the inner end was ball-and-socket jointed to a three-toe foot F; the point of each toe pressed on one end of a small steel rod, which passed freely through a guiding hole, its other end abutting against the back of the front disc D, immediately behind the seat of the spring S. Thus the three steel rods touched the back of the seat of the spring at three points, and the average of their measurements was delivered to the measuring rod M by the three-toe foot F. All the points of this system were kept in contact by a small spiral spring, Fig. 4, pressing with a definite force behind the ball of the measuring rod M.

The position of the outer end of the main spring S was defined by two studs T, Fig. 4, Plate 26, projecting diametrically opposite each other from the washer which was between the nut N and the end of the spring S. These two studs were touched by two notches in a gimbal ring G, by which their position was averaged, and were connected with a frame A containing a micrometer screw E. The true length of the spring S was obtained by screwing up the micrometer screw E until its point just touched the point of the measuring rod M. The frame A containing the micrometer screw, being rather delicate, was removed while an experiment was being made; and was applied only when an alteration or adjustment of the force of the spring S was required.

It will be observed that this measuring system was entirely free from any strain applied to the spring, and also from any

alteration of zero caused by the wear of the working surfaces. The scale of the spring S was found by putting the apparatus in a vertical position, and hanging weights on the driving shaft H, Fig. 1, and then reading off the micrometer. The weights corresponding with the arbitrary divisions of the micrometer were thus ascertained. The scale of the spring was about 7,000 lbs. per inch. The micrometer screw had 35 threads per inch, and its head was divided into tenths and hundredths of its circumference; thus one hundredth of a turn of the screw was equal to about 2 lbs.; and in testing the spring it was found that on repeating a test the reading of the micrometer could be depended on repeating itself within about that amount.

Lubrication.—The method of lubrication adopted was one which is in practical use for collar bearings, and which seemed by the light of our previous experiments to be a good one. It consisted of four grooves cut in each face of the ring R, Fig. 5, Plate 27, $\frac{1}{4}$ inch wide and $\frac{3}{4}$ inch long, arranged in a diametrical direction and so that each end of the groove was 1-8th inch inside the edge of the bearing surface. From each of these grooves there extended in the direction of motion of the surfaces a shallow groove about 1-10th inch wide and of a serpentine form, tapering away to nothing in about $3\frac{1}{2}$ inches length. These grooves were each supplied by a pipe P, into the mouth of which oil was dropped from a small cock connected with an oil tank K, so that the rate of supply to each set of grooves was easily seen and regulated, and uniformity of supply was secured. As we were led to expect by our previous experience, the magnitude of the friction depended considerably on the rate of lubrication; but we soon found a minimum rate of lubrication with which the bearing would work safely, such that, if the lubrication was less, the bearing would show signs of seizing by rapid variations of friction and by a jerking of the lever; and if it was much more, the friction, though less, was not reduced in proportion to the increase of the oil supply, and consequently it might be assumed that the oil was being wasted. This minimum safe rate of oil supply, with which the friction recorded in the Tables corresponds, varied from 60 to 120 drops per minute for

both faces, the quantity varying with the speed and load. The oil used throughout was a mineral lubricating oil.

Results of the Experiments.—The machine was run for a week with varying loads, in order to bring the surfaces into a proper working condition before the experiments recorded in the Tables were begun. The experiments were tried in the order shown in Table XIV (page 178), the variations of load being run through with the lowest speed first, then with the next, and so on till the highest speed was reached. Except with the lowest loads it was found impossible to keep the bearing cool without a little water running over it. The friction given in the Tables is that of one face of the annular bearing surfaces, at the mean radius of the face, namely 6½ inches.

It will be seen from Table XIV that the revolutions per minute were not very constant, owing to the varying speed of the shafting by which the machine was driven. The variation in speed however was but small in each individual experiment, not amounting to more than 1 per cent. above or below the speeds given in Table XIV. In order that the results might be plotted on a diagram, it has been necessary to reduce the results to regular speeds at regular intervals by interpolation. The speeds taken were 50, 70, 90, 110, and 130 revolutions per minute; and the results so reduced are given in Table XV (page 179), from which is plotted the diagram shown in Fig. 10, Plate 28. When examining this diagram, it must be remembered that the friction varies somewhat with the rate of lubrication, and that the minimum safe rate of lubrication is not very exactly defined; this must explain one or two slight irregularities in the diagram. For instance with loads of 1,200 and 2,400 lbs. there can be no doubt that at 50 revolutions the rate of lubrication was too great, and the friction consequently somewhat too small; and that, if the experiments were repeated, there would be no difficulty, by reducing the oil supply, in bringing the friction more nearly to agree with that of the other speeds. But in these experiments all such adjustments were carefully avoided, as tending to deprive the experiments of value. Nevertheless in the majority of instances the results are extremely well defined, and point to the fact that the friction is independent of the speed. For instance,

with a load of 1,200 lbs. four different speeds—namely 90, 110, 70, and 130 revolutions per minute—give the same friction so nearly that the greatest variation from the mean is only 2·19 per cent. With a load of 1,800 lbs. four different speeds—namely 130, 90, 50, and 110 revolutions—give the same friction so nearly that the greatest variation from the mean is only 2·57 per cent. With a load of 2,400 lbs. and three different speeds—namely 70, 110, and 90 revolutions—there is a variation of only 2·29 per cent. from the mean friction. Again with a load of 3,000 lbs. the greatest variation from the mean with five speeds—namely 130, 110, 90, 50, and 70 revolutions per minute—is only 2·12 per cent. The above speeds are given in the order of the magnitude of the friction; and in these small variations it does not appear that there is any well-defined connection between the speed and the friction. For instance, with 1,200 lbs. the highest speed gave the lowest friction, while the reverse was the case with the higher loads. Thus out of twenty experiments the results of sixteen agree with one another so nearly that the greatest variation from the mean is only 2·57 per cent.; an agreement so close that we think we may with confidence accept their testimony, and reject the remaining four. The diagram shown in Fig. 11, Plate 28, is plotted in this way, and may be considered to sum up generally the results of the experiments.

General Conclusions.—This kind of bearing is evidently very inferior to a cylindrical journal in its power of carrying weight; 3,000 lbs. on 40 square inches, or 75 lbs. per square inch, was as much as it would bear safely at the highest speed, though it carried 90 lbs. per square inch at the lowest. The coefficient of friction is also much higher than for a cylindrical bearing, and the friction follows the law of the friction of solids much more nearly than that of liquids. All this is doubtless due to the much less perfect lubrication applicable to this form of bearing compared with a cylindrical one. The coefficient of friction appears to be about the same with the same load at all speeds, or in other words to be independent of the speed; but it seems to diminish somewhat as the load is increased, and may be stated approximately as 1-20th at 15 lbs. per square inch, diminishing to 1-30th at 75 lbs. per square inch.

TABLE XIV.—*Experiments on the Friction of a Collar Bearing. Results obtained from the machine.*

The Friction given is that of one face of the annular bearing surfaces, at the mean radius of the face, namely 6½ inches.

Revolutions per min.	Total Load.	Friction. Total.	Friction. Coefficient.	Temperature of Air.	Remarks.
No.	Lbs.	Lbs.		Fahr.	
51	600	27·5	0·0458	68	Without water
48	1200	43·7	0·0364	68	do.
42	1800	61·2	0·0340	68	With water
44	2400	62·5	0·0264	68	do.
48	2700	96·2	0·0356	82	do.
43	3000	105·0	0·0350	68	do.
50	3300	111·2	0·0337	68	do.
50	3600	112·5	0·0312	68	do.
70	600	38·7	0·0646	69	With water
68	1200	57·5	0·0479	69	do.
72	1800	72·5	0·0403	72	do.
70	2400	90·0	0·0375	72	do.
68	2700	90·0	0·0333	69	do.
70	3000	102·5	0·0341	72	do.
70	3300	106·2	0·0322	69	do.
68	3600	155·0	0·0430	72	do.
87	600	25·0	0·0416	62	Without water
94	1200	60·0	0·0500	62	With water
96	1800	62·5	0·0347	62	do.
100	2400	85·0	0·0354	80	do.
100	2700	95·0	0·0352	72	do.
96	3000	105·0	0·0350	72	do.
99	3300	118·7	0·0360	82	do.
	3600				Seized
127	600	37·5	0·0625	72	With water
124	1200	57·5	0·0479	72	do.
126	1800	66·2	0·0368	68	do.
145	2400	105·0	0·0437	68	do.
142	2700	105·0	0·0389	75	do.
120	3000	106·2	0·0354	68	do.
	3300				Seized
	3600				Seized

TABLE XV.—*Experiments on the Friction of a Collar Bearing.*
Results of Table XIV *reduced to uniform Speeds.*
See Plate 28, *Fig.* 10.

The Friction given is that of one face of the annular bearing surfaces, at the mean radius of the face, namely 6½ *inches.*

Speed.	Total Load.	Friction. Total.	Friction. Coefficient.
	Lbs.	Lbs.	
50 revolutions per minute.	600	27·0	0·0450
	1200	45·0	0·0375
	1800	64·2	0·0357
	2400	68·7	0·0286
	2700	95·5	0·0354
	3000	104·2	0·0347
	3300	111·2	0·0337
	3600	112·5	0·0312
70 revolutions per minute.	600	38·7	0·0646
	1200	57·7	0·0481
	1800	71·7	0·0399
	2400	90·0	0·0375
	2700	90·2	0·0334
	3000	102·5	0·0341
	3300	106·2	0·0322
	3600	160·0	0·0444
90 revolutions per minute.	600	26·0	0·0433
	1200	59·5	0·0496
	1800	65·0	0·0361
	2400	86·7	0·0361
	2700	93·5	0·0346
	3000	104·5	0·0348
	3300	114·7	0·0348
	3600		
110 revolutions per minute.	600	32·2	0·0537
	1200	58·7	0·0489
	1800	64·2	0·0357
	2400	89·5	0·0373
	2700	97·5	0·0361
	3000	105·7	0·0352
	3300		
	3600		
130 revolutions per minute.	600	38·5	0·0642
	1200	57·0	0·0475
	1800	66·7	0·0371
	2400	98·5	0·0410
	2700	102·0	0·0378
	3000	106·7	0·0356
	3300		
	3600		

Discussion.

The PRESIDENT said the question of friction was naturally one of the most important that an engineer could deal with. The Council had great faith in this Research Committee, and were gladly spending a considerable amount of money upon these experiments. Engineers would agree that many of their ideas about friction had been entirely upset by some of the experiments carried out by this Committee. It was thought desirable by the Council that the experiments of which the results had been given in the Report now read should be still further continued in the direction of bearings for vertical and other shafts subjected to end thrust. He hoped therefore that any one who had any information on this subject would kindly suggest in the present discussion any experiments which he considered should be carried out; because it was only by the combined intelligence of all who were versed in this matter that the experiments could be properly conducted, so as to avoid going over unnecessary ground. The Committee were now in communication with Sir Henry Bessemer, who had had large experience in bearings for small high-speed vertical spindles; and he had most kindly offered to put all his experience on this subject at their disposal. If any other Member could similarly put experiments at the disposal of the Committee, they would be only too glad to consider them, and to take advantage of any suggestions which might be offered. A communication respecting this Third Report had been received from one of the Members who was unable to be present, which it would be well to read before the discussion began; and he would then call on Mr. Tomlinson, who was the Chairman of the Friction Committee, and to whom they were very much indebted for conducting the experiments, to open the discussion.

Mr. ALEXANDER TURNBULL wrote that the experiments as they were given in Table XIV did not seem to be so satisfactory as could be wished, and did not show such an amount of uniformity as might be expected, seeing that they were conducted with such care. The great variation in the amount of friction caused by varying the load

was a matter which required some explanation. On deducing from Table XV the increase of friction due to increasing the load by 600 lbs. at a time, it would be seen from the following figures that the

Speed.	Increase of Friction for every additional 600 lbs. of Load.					
Revs. per min.	600 to 1200	1200 to 1800	1800 to 2400	2400 to 3000	3000 to 3600	Average Difference.
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
50	18·0	19·2	4·5	35·5	8·3	17·1
70	19·0	14·0	18·3	12·5	57·5	24·2
90	33·5	5·5	21·7	17·8	..	19·6
110	26·5	5·5	25·3	16·2	..	18·3
130	18·5	9·7	31·8	8·2	..	17·0

results were most irregular, and were not sufficiently accurate to be of much service. In view of such irregularities, and having himself had some experience in designing machines and likewise in the behaviour of spiral springs, he had directed his attention to the construction of the machine used in these experiments; and while it must be admitted that the machine was of a most ingenious construction, it could not be regarded as simple and reliable, because it possessed too many moving parts; inclusive of two portions of ball-and-socket bearings, there were about a dozen points or surfaces which must be in contact in order to obtain an accurate measurement of the spring. Another matter of great importance was the washer between the compressing nut N, Fig. 4, Plate 26, and the end of the spring, which did not appear to be so made as to prevent it from turning when the nut was being turned. But unless the washer was made to slide on the shaft by a feather or key, so as to prevent the coiling or uncoiling of the spring when the nut was being turned, it would seem not difficult to account for such erratic results as were shown by Table XV to have occurred at 70 revolutions, where an increase of 300 lbs. in the load, from 2400 lbs. to 2700 lbs., was attended with

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an increase in friction of only 0·2 lb., while for a further addition of 300 lbs., from 2700 lbs. to 3000 lbs., the increase in friction was 12·3 lbs., or over sixty times the former increase. It was therefore to be hoped that these experiments might be supplemented by others, made if possible with a machine of more simple construction. In a machine designed by himself, which was a modification of that used in these experiments, the effect of wear of the friction ring was eliminated, and the measurement of the spring was taken direct from opposite diametrical points on the abutting washers, the four points being in the same plane; and the mean of the two measurements was taken for each respective load.

Mr. JOSEPH TOMLINSON, Vice-President, said these experiments were a continuation of those previously made upon the ordinary rolling bearings of an axle. The object in view in commencing the present series had been to try the most difficult form of bearing to lubricate; and he thought they had succeeded perfectly in this object, because the surfaces of the collar bearing here tried were never relieved from each other by any vibration, but were held always steadily in close contact. Not having had the advantage of Mr. Turnbull's suggestions at the time of designing the experimental apparatus, many hours had been spent by Mr. Mair, Mr. Tower, and himself, in designing an apparatus which would really give the loads required without cumbersomeness; and he thought it could not have been planned much better for that purpose. The experiments had proved conclusively that friction meant non-lubrication; and this was the true definition of friction. In the first series of experiments (Proceedings 1883, page 632) trials had been made of bearings lubricated in all kinds of ways; but when they got the axle running in a perfect bath of oil, and could give it even the least amount of shake or vibration, the coefficient of friction immediately went down to a very small fraction of what it had hitherto been considered to be. They had now wanted to try the worst condition of bearing it was possible to have. The collar bearing here experimented upon was of course to a certain extent what was met with in a ship; but the propeller shaft and the thrust blocks in the ship were never in actual

contact for a length of time together, as this experimental collar bearing was; and therefore he thought these experiments went still further to prove that it was the lubrication which was the real measure of friction, for here they had indeed the very worst form of bearing into which to get the lubricant to enter. In the carrying out of these trials a large amount of time had been spent by Mr. Tower, and also by Mr. Mair and himself, in order to arrive at correct results; but he was unable to account fully for the two kinks which occurred in the middle of the diagram, Fig. 11, Plate 28. It had not been thought advisable to attempt to remedy these; but if the upper corner were carried a very little higher up and the lower were moved a very little lower down, they would both be brought into almost a straight line. It seemed clear to him therefore that from some cause or other the lubricant had not been working so well at that particular stage of the trials as it did at the others. He should be very happy to make the experiments again with the advice and assistance of anyone else, particularly if it could be shown how to make a simpler machine to carry the same loads. He was now about scheming with Mr. Tower a machine to carry the experiments further in the way of pivot bearings, both for high speeds and for heavy loads; but such trials would not be very easy to make, because in dealing with loads varying from 600 lbs. up to 3000 and 3600 lbs. there was a great deal of difficulty in so contriving a machine that it would work through so long a range of load. In this respect the present series of experiments had answered fairly well; and if the mean of the lower experiments were taken, and also the mean of the higher, and a straight line were drawn joining them, this line would represent pretty nearly the true coefficient of friction right throughout.

Mr. W. Ford Smith observed that one point which did not seem to be touched upon in the report was the quality of the metal surfaces brought into contact. This seemed to him to be most important, even more so than the extent of the bearing surface or the pressure per square inch upon it. In steel shafts made with some of the soft steel now used it was possible that a very small

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amount of pressure would cause the two rubbing surfaces to work badly, and one surface would tear the other. When they were so exceedingly soft they seemed to partake somewhat of the nature of lead, and they seized or "galled" into each other, as it was termed. Directly seizing commenced, hardly any amount of power would drive the pieces; they adhered to each other and became almost one solid mass. But in practice, when he had had any difficulty of that kind, it had been got over in the first place by increasing the bearing surfaces, so as to reduce the pressure per square inch. If that had not been found to be sufficient, the next recourse had been to hardening the surface of the steel, and grinding it up to a beautiful face, and then letting it work upon a surface of dense cast-iron. If that had not succeeded, he had then had recourse to hardened steel working upon hardened steel. One practical experiment which he had made had been with an upright shaft 40 feet long and 2¼ inches diameter. The whole weight of the shaft came upon the bottom bearing, which was only 2¼ inches diameter, the same diameter as the shaft itself. On this bearing there was not only the weight of the shaft, but also that of three heavy couplings, and of four heavy wheels carried upon the shaft; and the vertical pressure on the lower end of the shaft where it rested on the washers was consequently 455 lbs. per square inch. The fear of any trouble taking place led him to try the plan shown in Figs. 15 to 17, Plate 30. A hardened steel washer was introduced at the bottom of the shaft, and another at the bottom of the footstep, and between them were inserted two similar hardened washers; none of them were fixed in any way, but they were all left loose and perfectly free to revolve. Through the centre of all four was drilled an oil hole, which communicated at bottom by means of four radial oil holes under the washers with four channels C down the sides of the footstep; and the washers themselves were also grooved radially from the centre hole, so that the centrifugal force threw the oil continuously outwards and upwards to the top of the footstep, whence it was free to descend to the bottom and circulate again and again. In that way he presumed a complete circulation of the oil was kept up, with the result that the shaft had now been working daily for some twelve

years, and frequently working overtime, and there had never been the slightest trouble with it.

Similarly in the case of other vertical shafts, such as the spindles of drilling machines for instance, as shown in Figs. 18 and 19, Plate 30, where a downward pressure had to be transmitted to the drill spindle D from the square-threaded feeding screw S, the difficulty was met in the same way by fixing a hardened steel washer on the bottom of the screw, and a corresponding one on the shoulder of the spindle. Here the washers had been increased in diameter for the sake of getting larger bearing surfaces; and they were provided with oil-holes, and grooved on their faces for enabling the oil to get through, as shown in the plan, Fig. 18. What the actual pressure would be he did not know; but he had used this plan for 3-inch twist drills that were drilling out of the solid, making 100 revolutions per inch in depth, so that the pressure must have been very considerable. No cases had occurred of galling or seizing; and though there might have been a very slight amount of heating, it had not been sufficient to necessitate the stoppage of the machines. In his own experience he had found that, when it was not convenient to use washers of larger diameter than the drill spindle, the difficulties were overcome by increasing the number of the washers to four, as shown in Figs. 20 and 21, Plate 30.

Again, in the case of horizontal bearings where there had been an end thrust occasioning any difficulty, he had similarly modified the bearing by introducing a series of hardened steel washers, left loose to run free, as shown in Figs. 22 and 23, Plate 30. The same plan had been carried out also by Mr. Edward Reynolds in Sheffield, in connection with exceedingly heavy pressures. In his own experience there was no difficulty whatever with this plan; it was simply a matter of putting in a sufficient number of steel washers to take the pressure, thereby obtaining a multiplication of rubbing surfaces, which slipped over one another at differential speeds, according as the friction happened to vary between them.

With regard to soft steel being unsuitable for shafts, he had unfortunately had some shafts of such exceedingly soft steel that when the shaft had been turned to anything like a good fit, and had

(Mr. W. Ford Smith.)

been pressed into a long cast-iron bearing, the very action of pressing it into its place had been sufficient to cause galling. Although it had been taken out and reduced a little in diameter, so as to allow for a thin film of oil between it and the cast-iron, yet even then it had galled a second time. In a case of that sort the only way to get rid of the difficulty was simply to case-harden the outside of the shaft in the ordinary manner with water, so as to produce a hardened steel surface, and then to grind it true for running in the bearing. When that had been done, the difficulty had been got over. But it was better carefully to avoid using soft steel for shafts, and to put the shafts in as hard as they could conveniently be made.

Professor W. Cawthorne Unwin noticed that at lower speeds the same bearing would carry a higher pressure per square inch than at higher speeds: which seemed to be connected with the dependence of the friction on the temperature, because at the lower speeds there would be less heat to carry away, and the bearing would run cooler. It would therefore have been of interest if something had been known about the temperature which the bearing reached in these experiments. Moreover a collar bearing of this description, working continuously at a constant speed and under a continuous pressure, was a very much more difficult case to deal with than where the bearing had to carry the pressure only a short time and then was relieved. No doubt in these experiments the bearing had been in the worst possible condition: the heat generated by continuous friction had to be dealt with continuously, and the point at which the bearing seized would depend in some way or other upon the temperature reached in consequence of the accumulation of heat in the bearing. It was a very curious result of these experiments that the friction was found to be independent of the speed, though not of the pressure; and it seemed to him to follow that somehow or other this independence of the speed was connected with the rate of lubrication in these experiments, because it appeared that the rate of lubrication was varied with the speed: as the speed got slower, a slower rate of lubrication was found sufficient. In moderately lubricated surfaces the law that the coefficient of friction was inversely as the square root of the pressure

and the square root of the speed seemed to come nearer than anything else.

Mr. William Schönheyder considered the general conclusion to be drawn from these experiments was evidently that a collar bearing was inferior to a cylindrical journal. This agreed with previous experience; for it was well known that a sliding surface could never carry such a heavy load as a journal surface. Whereas the journals of crank-pins could carry from 400 to 600 lbs. per square inch, the slide-blocks of a steam engine could not carry more than one-tenth of that pressure. The collar bearing tried in these experiments was very similar to the slide-block of a steam engine, and was just as difficult to lubricate. He did not quite see what object had been gained by these experiments, because in almost all of them it appeared from Table XIV that water had been used for cooling the bearing. If water was thrown on the surface of a bearing of any kind, it altered the conditions altogether, and there was no knowing what sort of lubrication was taking place, whether with water or with oil: such conditions indeed were not at all advisable in practice, nor would any engineer desire to have them. It would have been preferable he considered for this machine, or a better one if it could be made, to work under proper conditions, so as not to be over-pressed in any way, and so that it would work without any cooling with water. It would then be much more likely to furnish accurate results, which would be of some value for practical engineers. There seemed no reason why the bearing should be at all stinted of oil; the more oil it got the better, and provided there was no waste he thought plenty of oil should always be used.

Professor Archibald Barr said it was very interesting to see that these later experiments bore out the beautiful theory published some time ago by Professor Osborne Reynolds,* which explained in almost every particular the results that had been obtained with the cylindrical journal. Professor Reynolds had shown very clearly that

* Proceedings of the Royal Society of London, 11 Feb. 1886, vol. xl, page 191.

(Professor Archibald Barr.)

the small amount of friction in the case of the lubricated journal running in a bath of oil, as described in the Committee's first report, was due to the fact that the brass had not exactly the same radius as the journal, but a rather larger radius, as shown greatly exaggerated in Fig. 13, Plate 29, and therefore that the oil which was carried up from the oil bath was carried in between the brass and the bearing, and was practically jammed in between them, thereby supporting the brass and giving the admirable results which were got with the cylindrical journal. Such results of course could not be expected to be obtained with flat surfaces, where there was no action of that kind to carry the oil in continuously between them. In an end thrust bearing, the case which would correspond to some extent with that of the journal—and it might be interesting if the Committee could make an experiment upon it—would be, not to have an absolutely flat bearing surface, but to cut one or more radial oil grooves in it, and make the surface of the footstep very slightly screw-shaped, as indicated with great exaggeration in Fig. 14, Plate 29; then the oil in the groove would be carried round into the tapered clearance, and so carried in between the two surfaces.

The experimental apparatus described in the report, though admirably designed, appeared to him to be open to the objection that there was no means of altering the pressure during an experiment; and consequently the bearing could not be started without any pressure upon it, and with a good supply of oil, and then the pressure be gradually increased. At the present time he was occupied in designing a laboratory apparatus for experiments upon lubricated journals; and though he had not yet completed the design, it seemed to him that it would be possible to make a good machine by adopting some arrangement of a water-pressure diaphragm, say of india-rubber, with a strong plate in front of it and water pressure introduced behind, which could be varied at will, whereby the pressure on the bearing could easily be got up to the amount desired, even while the bearing was running. He asked where the oil mostly came out in these experiments. A large quantity of oil was put in, and it would be interesting to know whether it came out at the outer rim almost entirely, or whether it flowed out at both the outer and the inner rim.

In regard to the plotting of the diagram, Fig. 11, Plate 28, he suggested that, if its horizontal extent were made more nearly equal to its vertical height, it would be found that the line was not, as it had been said to be, almost a straight line, but that there was a very distinct amount of curvature in it. If instead of being made so high and narrow the diagram were extended in width so as to occupy about an equal space horizontally and vertically, that would give the curve the best form for showing the relative variations of the load and the friction.*

Mr. David Greig, Vice-President, considered it was essential not only that there should be a sufficient bearing surface for the speed, but also that air should be admitted freely to the bearing. Having had a great deal of trouble with an engine at the co-operative stores in Leeds, which had brasses beautifully fitted but no admission of air, he had found that, as soon as ever a proper admission of air under the bearings was provided for, the engine worked admirably. Without admission of air between the bearings and brasses, he was of opinion that the continuous flow of oil did not exist at all; the air was necessary not only for keeping the rubbing surfaces cool, but also for enabling the oil to circulate between them.

Mr. J. Hartley Wicksteed, Member of Council, desired to express his appreciation of the beautiful apparatus with which the experiments had been made, and the very instructive nature of the results obtained. One point of much interest was that the behaviour of the spiral spring had been so uniform and satisfactory. The spring appeared not to have varied more than 2 lbs. in 7,000 lbs., which was only 1-35th part of one per cent. That was a result which had been arrived at incidentally in these experiments, and one which was instructive because there were so few reliable instances of a spring having been so thoroughly well tried by repeated pressures applied to it, while the spring was so beautifully held as it was here by the spherical shackle.

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* The re-plotting of Fig. 11, Plate 28, in conformity with the above suggestion, is shown in Fig. 12, Plate 29.

(Mr. J. Hartley Wicksteed.)

The former series of experiments made upon cylindrical journals had shown that, when a cylindrical journal was lubricated from the side on which the pressure bore, 100 lbs. per square inch was the limit of pressure that it would carry; but when it came to be lubricated on the lower side and was allowed to drag the oil in with it, 600 lbs. per square inch was reached with impunity; and if the 600 lbs. per square inch, which was reckoned upon the full diameter of the bearing, came to be reckoned on the sixth part of the circle that was taking the greater proportion of the load, it followed that the pressure upon that part of the circle amounted to about 1,200 lbs. per square inch, or about half a ton per square inch. In the present experiments the collar bearing had failed at 80 lbs. per square inch, which he thought would be a considerable surprise to practical engineers. There was no doubt the experiment was correct, and that if it were wished to put a collar on under similar circumstances it must not be loaded with more than 80 lbs. per square inch; and he presumed that engineers would all begin to give more surface to collar thrust bearings. The result was surprising to himself for the reason that there were a great many instances in actual practice of thrust collars working at four times that pressure per square inch. The conditions however were not exactly the same, and the speed in such instances was very low. In a drilling machine for drilling a one-inch hole it would be a common proportion to have a spindle two inches diameter running at 100 revolutions per minute. In Fig. 24, Plate 31, supposing the drill spindle D to be two inches diameter, the sectional area was a little more than three square inches, but one square inch was taken off the bearing area by the shank that went up through the screw S. Hence the shoulder of the spindle was about two square inches area. The pressure required to force a one-inch drill through metal at any moderate speed amounted to 6 cwts. Therefore there was at least 3 cwts. or 336 lbs. per square inch upon the shoulder of the spindle, which would nevertheless go on working year after year with very little attention. No attention whatever was given to the lubrication, which was effected by the rudest possible means; there was just a little

groove G cut down the shank, and whatever oil could find its way into the shoulder did so; and if it could not find its way in, the drill ran without it. The construction was as shown in Fig. 24. A hardened steel washer, made as hard as it could be and ground true on both faces, was pinned on the soft shoulder of the spindle so as to revolve with it; and another hardened washer was pinned on the soft bottom of the screw. Between these two washers was a third hardened washer, also ground on both faces, which was not pinned but left loose, so that it was free either to revolve with the spindle or to stand fast with the screw or to revolve at an intermediate rate. The result was that the circumferential velocity of the loose washer did not much exceed 25 feet per minute, assuming that it was revolving at half the speed of the spindle, and that the spindle was running at 100 revolutions per minute. In the experiments now reported the speed appeared not to have gone lower than 150 feet per minute. This higher speed might therefore have something to do with the greater friction of the collar bearing; and the nature of the material probably had a great deal more to do with it. In the case of his lever testing machine, the thrust collar of the screw displacer which forced water into the hydraulic straining cylinder worked under a pressure that rose gradually from nothing at all up to as much as half a ton per square inch; by that time it was getting warm pretty fast, but still it did continue to turn round without seizing; it did not run very long under the extreme pressure, but left off as soon as the specimen broke, and then began again from nothing at all in the next test. The actual end pressure upon the screw, as measured by the steelyard of the testing machine, mounted up to a maximum of 12 tons, which was taken by a collar of 6 inches diameter on a shaft of 2½ inches diameter; this gave therefore a pressure of about half a ton per square inch just at the climax of the test, and then the experiment stopped. Considering that, as Mr. Tomlinson had said (page 182), the whole question of friction resolved itself into one of lubrication, it was highly gratifying to hear from the President that these experiments were going to be pursued further. The object evidently was now to find how to lubricate a thrust bearing efficiently; and the experiments should be carried out with

(Mr. J. Hartley Wicksteed.)

such a bearing as was used for screw-propeller shafts, where there were a series of collars which were working under a different condition from a collar with open circumference, like that tried in these experiments, because on the screw-propeller shafts every collar was closed in circumferentially and therefore the oil could not escape freely. Moreover in screw-propeller thrust-bearings the whole of the bottom part of the bearing was removed, so that the thrust-collars might work in a bath of oil and drag the oil up with them between the rubbing surfaces. He hoped therefore that the further experiments, besides being carried out in reference to an end thrust bearing, would also be so carried out as to see what was the best that could be made of a bearing similar to that of a screw-propeller shaft.

In confirmation of what Mr. Ford Smith had said, he agreed that in actual practice a good deal must depend upon the hardness or softness of the material used for the bearing surfaces, as well as upon the lubrication. In an instance of a sort of screwed bonnet prepared for going upon a screw, both being made of mild steel supposed to be Siemens steel, the bonnet was being screwed on by hand with nothing more than a turner's catch, and after the screw had entered the bonnet it seized so fast that no power could unscrew it, and the bonnet had to be ripped or split up on opposite sides with a parting tool before it could be got off. Heat was tried, and also very great twisting force, almost enough to twist the shaft in two; but the two threads were perfectly imbedded together, although the pressure on the surfaces was not more than had been produced in screwing the one upon the other by hand power.

Mr. W. D. SCOTT-MONCRIEFF noticed that the remarks made in page 176, with regard to the amount of lubrication, were at present vague; and until some advance had been made in the measurement of the liquid used in lubrication he was afraid they must remain to a great extent vague. In practice indeed the difference between sufficient and insufficient lubrication made not a slight difference in the result, but all the difference: from insufficient lubrication practically the same amount of harm might follow

as from no lubrication at all. There was therefore a very important work still to be carried out in ascertaining the details of the necessary amount of lubrication required for getting specific results such as were given in these Tables. A good many years ago he had been occupied with the late Mr. R. D. Napier in a number of experiments with regard to friction, at the time that Mr. Napier was engaged in perfecting his well-known differential clutch. At that time he had not been surprised to discover the great discrepancies that existed between the results of their own experiments and the results of experiments which had been made by previous authorities on the subject of friction. One discovery they had made was that there was a great difference between the effect of the lubrication with vegetable and with mineral oil, in relation to the speed of the moving parts, so much so that they acted in a manner inversely to each other: for in many of his experiments, while the friction increased with the increase of velocity in the case of vegetable oil, it decreased with increase of speed in using mineral lubricating oil. In the present report he noticed that reference was made to the use of mineral lubricating oil only; and he was not aware whether these experiments bore out the conclusions arrived at by Mr. Napier. It would be well perhaps that the Friction Committee should be furnished with all the information which Members had upon this subject; and it was with a distinct recollection of the surprise expressed by Mr. Napier at those results that he had thought it worth while to mention their experiments, which had been published in the Proceedings of the Philosophical Society of Glasgow (vol. ix, 1874, pages 188–201).

Mr. M. HOLROYD SMITH wished to take the opportunity of getting if possible a solution of a question which had puzzled him at a time when he had been making experiments with washers in much the same way as he now found that Mr. Ford Smith had also been trying them for many years. In his own case he had introduced them into some turbine work, in order to moderate the thrust of the turbine spindle. In one turbine he had found that they acted very successfully, but in another some difficulty had arisen from them. The theory that he

(Mr. M. Holroyd Smith.)
had gone upon was that of reducing the speed, just as had already been explained by Mr. Ford Smith (page 185), under the idea that the relative speed of the rubbing surfaces would be reduced in proportion to the number of loose washers that were introduced. But the notion that it was this reduction in speed which caused the reduction in friction seemed so directly contrary to the conclusion of the Research Committee, who reported the friction independent of the speed, that he thought some other cause of the diminished friction might be sought for than the reduction in speed. The true cause he believed to lie in the circumstance that by the interposition of the loose washers a kind of compensating balance was introduced, which had the effect of equalising the pressure over the bearing surfaces; and in this view he rather thought that some of the good results from the experiments now described were due to the ball-and-socket joint at the inner end of the bolt B in Fig. 4, Plate 26, by which the pressure of the spiral spring was equalised over the rubbing surfaces. It therefore occurred to him to suggest whether it would not be well, in supporting a heavy upright shaft, either to make the footstep in the same way that a mariner's compass was mounted, so that the pressure should always be equally distributed upon it; or else to hang it from the onion bearing described by Mr. Davey at the last meeting (Proceedings Feb. 1888, page 65), which constituted a swivel bearing at the top of the shaft. If the success which Mr. Ford Smith had achieved by the introduction of a number of washers might be looked upon as resulting more from the fact that the pile of washers acted as a kind of spring for equalising the pressure than from the reduction of speed of the rubbing surfaces, that view might serve to harmonise Mr. Smith's practical results with the theory of the Research Committee.

Besides giving diagrams of their experimental apparatus and of the results thereby arrived at, it would be a great advantage if the Research Committee could further reduce those results to practice, and show the kind of bearing which it would be best to use under varying circumstances. In Fig. 13, Plate 29, he was glad to see that Professor Barr had shown what was of course held by many

engineers to be the true explanation of the successful lubrication of a cylindrical bearing, namely that theoretically the bearing was touching only at one part, and that by the easing away of the surfaces leading up to that part the oil was enabled to get in there between them and keep them lubricated. In a thrust bearing therefore it had occurred to him that the bearing surface ought to depart somewhat from the true plane which was exactly at right angles to the line of thrust; and he had attempted pretty successfully to carry out that idea in making the thrust bearings for the worm-gearing which he had introduced for driving his electric tramcars. Anticipating great difficulty from the end thrust of the worm spindle, he had fitted the spindle with collars, of which the bearing faces, instead of being made square to the axis of the spindle, were slightly inclined from the right-angled position to the extent of about 4 or 5 degrees, as shown in Fig. 26, Plate 31, somewhat like the two faces of the worm itself. This plan of making the collars slightly conical or bevilled, instead of square, had been attended with a decided benefit in working; and the cap in which they ran was made easy, so that there should be a good circulation of oil between the bearing faces. Besides inducing a better flow of oil between the surfaces, the inclined collars had the further advantage of assisting in compensating better for any cross strain upon the spindle. It would be of much value, he considered, if some experiments could be made for ascertaining the best means of circulating the oil in these thrust bearings; and also some means for carrying out the suggestion sketched by Professor Barr in Fig. 14, Plate 29, in which he was much interested as a plan that had occurred independently to himself for allowing a flow of oil into the places where it could not otherwise get in. The shallow serpentine grooves shown in Fig. 5, Plate 27, did not appear to him to be altogether the best means of distributing the oil over the face of a collar bearing; and he should like to know whether anyone had ever tried, and if so with what result, a collar bearing of the kind shown in Fig. 28, Plate 31. The usual method was for the corner at the neck of the collar to be rounded into the shaft with a full curve, as shown in Fig. 27; but he was disposed to think that a much better

(Mr. M. Holroyd Smith.)

result would follow if, instead of the corner being rounded solid in that way, it were made with a hollow by slightly undercutting the collar at that part, as shown in Fig. 28, so as to leave a space there all round the shaft, into which the oil could be fed, accumulating there in a little pool, and flowing out thence over the rubbing surfaces by the aid of the centrifugal force. That was an experiment which he had determined to try when next he had an opportunity, if he could not succeed in learning of its having been tried already.

Another question in reference to lubrication was in what way the oil was regarded as acting. Did it come between the two rubbing surfaces as a film upon which each of them could then slide, like a steel skate sliding upon ice? Or did it represent the introduction of minute rollers between the bearing surfaces? If the latter, then why was not that theory followed up by introducing roller bearings as far as could possibly be done? Interesting experiments had indeed been tried in that direction; but he was afraid the first cost had thus far prohibited the use of roller bearings to the extent that they deserved. When himself making some experiments in connection with the subject of aërial navigation, with the object of showing the various actions of wings of different kinds, he had constructed a miniature turntable with three small conical rollers running live upon a path above and below; and when standing centrally upon it a slight motion of the wing was sufficient to turn him perfectly round. He should therefore like to know what experience there had been in the introduction of roller bearings, roller footsteps for heavy vertical shafts, and rollers for end-thrust bearings of horizontal shafts; and whether any compensating arrangement had been used for equalising the friction on the several rollers. It was obvious that, if only three rollers were used, any slight variations in their size would be immaterial; but if there were more than three, they would always have to be kept all the same size.

Mr. Daniel Adamson, Vice-President, considered it essential that the composition of the bronze which formed the bearing for the spindle should be known, as well as the character of the spindle

itself and of the lubricant that was used. In cotton mills, where small upright spindles carried in a bearing at their bottom end were running at 8,000 or 10,000 revolutions per minute, a thin mineral oil was used. From his earlier experience, which no doubt agreed with that of other engineers, he had come to the conclusion that sperm oil, which had formerly been such a favourite, did not reduce the friction to so great an extent as the thinner mineral oils now used. These were the oils that gave the best result, when running at high speed and under a light load; but the most substantial fatty animal oil must be used where there was a heavy load running at a lower speed, as in the case of heavy upright shafts for driving large cotton-mill machinery. Under difficult circumstances he considered the lubricant was the most important thing. No doubt this collar bearing was the most disagreeable kind of bearing to lubricate. There could be only one method of lubricating it naturally, namely by supplying the oil to the smallest diameter of the collar, whence it would then flow outwards by the centrifugal action of the collar when running. In Lancashire, where heavy upright shafts were carried on a small footstep bearing, he recalled an instance which he had previously mentioned (Proceedings 1885, page 65) where a weight of at least 20 tons was carried on a shaft of 5 inches diameter or say 20 square inches area, giving a pressure of one ton per square inch. The old practice had been to lubricate footstep bearings by supplying the oil through a centre hole from a box surrounding the footstep, and allowing it to flow outwards to the circumference as best it could. But self-lubrication from an oil box in a footstep bearing was not sufficient under a heavy load to maintain a steady outward flow of oil, so as to ensure the bearing being kept always lubricated. It was necessary actually to force the oil under the bearing by means of a pump; and by this means a shaft producing a pressure of 2,240 lbs. per square inch was now kept running with certainty and without any difficulty whatever, not for hours only but for months and years. The experiments described in the present report would do nothing to help engineering practice in regard to end-thrust bearings where the load was certainly upwards of 2,000 lbs. per square inch, and the speed

(Mr. Daniel Adamson.)
was that of a shaft of 5 inches diameter making from 190 to 200 revolutions per minute. In comparison with such pressures and speeds, those employed in the present experiments were too small to serve as a guide, while the thin mineral oils were not suitable for carrying heavy loads.

For heavy horizontal shafts, such as a fly-wheel shaft carrying 100 tons on two journals, the practice now established by his firm in Lancashire for getting oil into the bearings was to flatten the journal along one side throughout its whole length to the extent of about an eighth of an inch in width for each inch in diameter up to 8 inches diameter; above that size rather less flat in proportion to the diameter. At first sight it appeared alarming to get a continuous flat place coming round in every revolution of a heavily loaded shaft; yet it carried the oil effectually into the bearing, which ran much better in consequence than a truly cylindrical journal without a flat side.

Mr. Arthur Paget, Vice-President, considered that the friction of bearings was formerly supposed to be, and too often was actually, governed by the laws of the friction between solids; whereas the experiments of the Friction Committee had shown that the friction of bearings really was now a sort of cross between the friction between solids and the friction of solids in liquids. What he hoped the Committee would succeed in arriving at, as it would be of great value, was a mode of reducing the friction in all bearings to only the friction of solids in liquids, that is, without the solid surfaces ever coming into contact at all. Professor Barr's illustration of the journal (Fig. 13, Plate 29) contained in his opinion the pith of the whole arrangement that ought to be aimed at, which was to allow the oil to be dragged in between the bearing surfaces by the movement of the journal itself. Mr. Wicksteed had spoken (page 190) of a journal as bearing on the brass on one-sixth only of the circle; what was really wanted was to get it so that it should not bear on the brass at all, but should be running in liquid or literally floating on liquid. When that condition was reached, the friction would be reduced from that between solids to that of solids floating in liquids.

It appeared that there were great discrepancies in the pressures which different bearings would carry under different circumstances. The pressure that could be carried on the collar bearing described in the present report was only about 90 lbs. per square inch; whereas the former report had shown that a journal thoroughly lubricated would carry 600 lbs. per square inch. In cases where the pressure and the motion were perfectly constant and steady, without variation and without trembling, there was sometimes great difficulty in getting the oil in between the rubbing surfaces. He remembered Mr. Hawksley, when President of the Institution, commenting upon some of the results obtained from friction brakes (Proceedings 1876, page 241), and illustrating his view by supposing that a sliding body on a table had a horizontal cord attached to it, passing over a pulley at the edge of the table, with a weight suspended just heavy enough to keep the sliding body in uniform motion; he then pointed out that, if the underside of the table were tapped with a quick succession of raps, the sliding body would travel much faster, owing simply to the relief from friction that was caused by the vibration or dither produced by the rapping. Now a journal such as that of a drill spindle which Mr. Ford Smith had fitted with hardened steel washers (page 185) did often dither or tremble to a certain degree in working; and it was this dithering that allowed the lubricant to get in between the rubbing surfaces and produce the effect of liquid friction; whereas in these latest experiments on a collar bearing the lubrication did not seem to have been so facilitated, and the friction had accordingly been that between solids imperfectly lubricated. These experiments he therefore hoped would be repeated in such a manner as might secure more perfect lubrication, when he anticipated that the results would more nearly approximate to those given by the former experiments on journal friction.

Mr. John G. Mair pointed out that in the experimental apparatus illustrated in Plates 25 to 27 the whole of the parts shown in Plate 26 revolved, with the exception only of the ring R, which was held stationary; and owing to the narrow width of that ring the speeds

(Mr. John G. Mair.)
at its outer and inner circumferences were very nearly identical. It was therefore an exceedingly difficult matter to get any oil in at all. It was certainly not in any way the same case as that of a pivot bearing, or even of a broad collar bearing, where the difference of speed was so great that oil fed to the inside would readily pass through to the outside. The ring experimented upon was more like the thrust or collar bearing of a screw shaft. After these experiments had been completed, he believed it was the intention of the Committee to experiment with pivot bearings; and undoubtedly with a pivot bearing, where the friction acted practically at no speed at the centre and at the maximum speed at the circumference, much heavier pressures would be carried than were possible to be obtained with a narrow ring, where the inside and the outside speed were so very little different.

With regard to the quality of the metal, the ring R was made of Landore-Siemens steel, not a hard but a mild steel. The metal faces on each side of it were phosphor bronze. Of course it would have been easy enough to make a set of experiments upon different kinds of metal; but that had not been the aim of the Committee, who had merely tried this ring in order to ascertain what pressure they could get upon a running ring; and also what the friction would be upon such a surface, which was the nearest approach that could be obtained to a plain flat surface with continuous motion in the same direction without reciprocation.

Mr. Beauchamp Tower, replying to Mr. Turnbull's comment (page 180) upon the irregularities in the diagram, Fig. 10, Plate 28, said that the lines plotted in that diagram were more regular than his own experience of the friction of lubricated bearings had led him to expect them to be. The fact was that the friction depended on the quantity of the lubrication, while the only guide as to whether a proper amount of lubrication was being provided was the friction. It would indeed have been easy to draw a good theoretical diagram, and then by regulating the lubrication to adjust the friction to the diagram; but he hardly thought the Members would have cared to have the experiments carried out in that way. What the

Committee had done was to regulate the lubrication as carefully as they could, so that the bearing should run cool, but without an excessive amount of lubrication. The friction was then noted and plotted on the diagram; and the plotting of each experiment was done without any reference to what had been done in the previous experiments; hence it could not be wondered at that the grouping of the results was not absolutely a straight line, though it was very nearly so.

Respecting the complexity of the apparatus, a sketch had been kindly sent by Mr. Turnbull of the apparatus he proposed, which differed from that used in the experiments in having the centre-bolt B, Fig. 4, Plate 26, made solid with the shaft H, instead of being ball-and-socketed to it; and it was proposed to cause the inner end of the spring to press on the disc D through a ball-and-socket bearing. That was an arrangement which had occurred to the Committee at an early stage of their design; but it had been abandoned, because, in order to carry out the principle thoroughly and prevent the spring from exerting a sideway force on the disc, another ball-and-socket or gimbal bearing would have been necessary at the outer end of the spring, which would have made it a more complicated method without being more efficient than that adopted.

With regard to the nut N turning the spring round with it in screwing up, they had experimented most carefully and exhaustively with weights put on the spring and taken off again, up to about 4 tons; and after taking great pains to make sure that every part of the apparatus was doing its duty, they had got the results to agree to within one division of the micrometer, which was equivalent to 2 lbs.; that is to say, they could put 4 tons on, read the measurement, take all the weight off, put the 4 tons on again, and the second reading of the micrometer would agree with the first within about 2 lbs. He had therefore not the smallest doubt that the loads recorded in the experiments were really within about that amount of the actual loads on the bearing.

The different qualities of metals no doubt affected the working of bearings to a great extent; but the object of the present experiments

(Mr. Beauchamp Tower.)

had been to try a collar bearing such as was used in practice on screw-shafts, and with the kind of materials and the methods of lubrication which were ordinarily used, and to ascertain what was about the amount of friction which practically occurred. Of course the number of variations that might be made in the method of lubrication and in the different qualities of metals was so enormous that a lifetime might be spent in investigating only one form of bearing; and it had therefore been necessary to limit the experiments within a narrow range. Professor Unwin recognised (page 186) that the real fact was that the quantity of heat generated was the true limit to the amount of load which a bearing would carry; and there was not the slightest doubt that this was so. When once a bearing began to heat, and the oil began to get heated up and lost its body, it ceased to have the power of carrying a weight.

The fact that the friction was independent of the speed had also been explained by Professor Unwin (page 186) as being connected with the rate of lubrication, which was varied with the speed; whether this explanation was the true one or not, the fact itself certainly appeared to be beyond doubt, from the very close agreement which several of the experiments showed on this point. No doubt Professor Unwin had in mind the previous experiments on journal friction, in which the friction somewhat increased with the speed, and in which in fact the friction followed the law of friction of liquids more nearly than that of solids. On the contrary it appeared to be more nearly the friction of solids than of liquids, which had been dealt with in the present experiments on a collar bearing. It was impossible however to give the precise reason why in this particular case the friction was independent of the speed; but the fact might be accepted that it had been found so.

In regard to running the water on the bearings in these experiments (page 187), he believed it was the fact that in all cases the thrust bearings of screw-propeller shafts were jacketed with water. This particular form of collar bearing, running at the speed and pressure that it did in such cases, was the most difficult of all forms of bearing to lubricate. The consequence was a high coefficient of friction, owing to the inefficient lubrication; and that

friction generated a certain amount of heat, which had to be carried away, or if it was not carried away the bearing would very soon cease to run at all.

The circumstance that the load could not be varied during the running of the experiment had been pointed out by Professor Barr (page 188), who had also suggested the use of a water-pressure diaphragm for the purpose. Curiously enough, when recently discussing the method of designing an apparatus for trying footstep bearings, it had occurred to Mr. Tomlinson and himself that probably the best way of applying pressure to the footstep bearing would be one very similar to what Professor Barr proposed. They contemplated using what would really be a small hydraulic press to put the pressure on the bearing; and the amount of the pressure would be simply indicated by a pressure-gauge. They were going to use oil in the press, and make the ram work in a grooved collar without any leathers, and allow the oil to leak, so that the ram would work perfectly free from friction through the collar. In that way they believed the pressure could easily be applied, without having to shift any weights or screw up any spring.

The desirability of ventilating the bearing had been urged by Mr. Greig (page 189). That was merely another way of stating the necessity for carrying away the heat which was generated by the bearing.

In regard to the surprise expressed by Mr. Wicksteed (page 190) at the small amount of load which this form of collar bearing would carry, he might mention that just after these experiments had been tried he had happened to meet Mr. Thornycroft, and without telling him what results had been obtained he asked him what load he ordinarily put on a thrust bearing in one of his torpedo boats. His reply was, never more than 50 lbs. per square inch: and thus the limit of 70 to 80 lbs. arrived at in the experiments received a very satisfactory confirmation from his extensive practical experience of the working of similar collar bearings. The results were of course different in the cases of drilling machines and other footstep bearings; these were simply different kinds of bearings which the Committee hoped in future to have a chance of investigating; but they

(Mr. Beauchamp Tower.)
differed in nature from the collar bearings tried in the recent experiments.

The measurement of the quantity of lubrication had been spoken of by Mr. Scott-Moncrieff (page 192); and also the difference between mineral and vegetable oils. The rate at which the lubrication had been applied had been governed by the way in which the bearing ran; and this was really the only practical means they had had of measuring it at all. The nature of the different oils had been thoroughly investigated in the first series of experiments with cylindrical journals (Proceedings 1883, page 632); and the results obtained with different kinds of oil—animal, vegetable, and mineral—had been very completely set forth.

For cylindrical bearings he doubted whether roller bearings, of which Mr. Holroyd Smith had spoken (page 196), were as good as ordinary lubricated bearings. The extremely low friction that was found in cylindrical bearings lubricated with an oil bath explained why cylindrical bearings so lubricated with oil had hitherto practically held their own against any form of roller bearing.

The very high load carried by a footstep bearing had been mentioned by Mr. Adamson (page 197), who had explained that the lubrication was maintained by a force-pump supplying the oil underneath. That was perfectly intelligible; and when the Committee came to experiment with footstep bearings he had not the smallest doubt they would find that by using a force-pump to supply the oil they would be able to effect a very great diminution of friction, and in fact would be able completely to support the bearing on oil by that means. With a very slight packing round a footstep it would be possible to make absolutely sure that the whole bearing was carried on oil, and that there was nothing but the friction of the oil on the metal; and a very small force-pump would supply the small amount of leakage which would escape past the packing.

As pointed out by Mr. Paget (page 198), it was quite true that lubricated friction was a cross between the friction of solids and that of liquids. The more nearly therefore the friction of bearings could be made to approximate to that of liquids, the better for all mechanical purposes in which bearings of any kind had to be employed.

The President believed the Friction Committee would be very well satisfied with the interesting discussion which had now taken place upon their report, and no doubt they would take advantage of all that had been said. He was sure that all the Members would join in cordially thanking the Committee, and Mr. Tomlinson, Mr. Mair, and Mr. Tower, for conducting these experiments on behalf of the Institution.

DESCRIPTION OF EMERY'S TESTING MACHINE.

By Mr. HENRY R. TOWNE, of Stamford, Connecticut, U.S.A.

Almost from the commencement of modern engineering practice the need has been recognised of obtaining accurate knowledge of the Strength of Materials as a basis for all work of design and construction; and the earlier engineers addressed themselves to this object with an earnestness and intelligence which will always command admiration, especially in view of the fact that the circumstances of their times required all such work to be done at their own expense, and usually with their own hands and heads. The ability which they brought to bear upon it, and the thoroughness with which it was accomplished, are best evidenced by the fact that the determinations of Tredgold, Buchanan, Rennie, and many others, were accepted by the engineering profession at large for more than half a century, and have only recently been superseded by the more accurate and extensive determinations of later investigators, assisted by modern appliances, and often aided materially by governmental support.

Nearly all the earlier determinations of the strength of metals, whether made by the older authorities above named, or by the succeeding group, represented by Fairbairn, Stephenson, Clark, Kirkaldy, and many others, were based upon small specimens, of which the greatest transverse dimension rarely exceeded one inch. The coefficients determined from these small specimens were for a long time accepted as a true index of the resistance per unit of section in all structural members composed of the same material, whether of large or small size. In recent years however, engineers have had forced upon their attention the fact that material produced

and used in large masses does not generally possess the same physical qualities as in the smaller and carefully prepared forms that were usually adopted in making the earlier experimental investigations. All doubts on this point were speedily dispelled, as soon as testing appliances were provided, however crude, of capacity sufficient to test specimens of even the smallest sizes usually employed in engineering construction. As a result the present tendency is towards the multiplication of testing machines, for enabling every large engineering works to test the whole of its important material; and is still more markedly in the direction of employing machines of such capacity and strength as to enable material of all kinds and of nearly all dimensions used in practice to be tested up to the point of deformation or destruction.

In the United States the importance of this matter was early recognised and discussed, with the result that in 1875 a committee was appointed by Congress for the special object of conducting investigations in regard to the strength of materials, and funds were appropriated for the purpose. This body, which became known as the United States Board for testing iron, steel, and other materials, entered upon their work in 1875, and during that and the succeeding three or four years made a great number of experimental investigations which were subsequently published by the United States Government, and have been of great value. One of the most important actions of the board, and the one which probably constitutes their chief monument, was the acquisition of the 400-ton (American ton of 2000 lbs., 400 tons American = 357 tons English) testing machine erected at the U.S. Arsenal at Watertown, Massachusetts, and still situated there. From the commencement of their work, the board recognised the importance of securing a testing machine possessing a degree of accuracy far greater than had previously been attained, and enabling it to be justly ranked as an instrument of precision. A machine of 800,000 lbs. or 357 tons capacity was accordingly ordered from Mr. A. H. Emery of New York, which was guaranteed by the maker to possess the stipulated qualities of precision, endurance, and general adaptability to the work. The machine was completed and put into use in 1879, since which year it has been in

constant service, having tested up to the present time more than 15,000 specimens, of dimensions varying throughout the entire range of its capacity. It was subjected originally to a test load of 1,000,000 lbs. or 25 per cent. beyond its intended limit. The largest section of wrought iron that has been broken in it had a diameter of 5·04 inches, or an area of 20 square inches. The machine will test in tension specimens up to 28 feet long by 30 inches wide, and in compression columns up to 30 feet long. Its sensitiveness is such as to show distinctly on the indicator a force of only one pound applied to the specimen. During all its years of constant service, it has maintained unimpaired its efficiency, accuracy, and sensitiveness, and is to-day as perfect in its action as when first erected; its mechanism is remarkable as well for originality as for perfection.

During the past five years the construction of testing machines on Emery's system has been regularly carried on in the works of the Yale and Towne Manufacturing Co., Stamford, Connecticut, under the direction of the writer, where numerous machines have been built of various dimensions and capacities adapted to the requirements of commercial work. It is therefore believed that a description of one of these machines, including what is novel and worthy of remark in its details, will not be without interest to English engineers. The designs selected for description are those for a vertical testing machine of 300,000 lbs. or 133 English tons capacity, two of which have already been built and have proved exceptionally excellent in actual service. The accompanying Plates 32 to 42 illustrate clearly the construction of this machine.

Principles of Emery's Machine.—In the broad principles of construction on which Emery's system of testing and weighing rests are included two radically new and highly important elements, namely :—

(1) An arrangement of hydraulic chambers and diaphragms, capable of receiving without injury pressures and shocks of great intensity, and of transmitting these simultaneously, without loss from friction, to a convenient point for the purpose of measuring

and recording them; and capable also of reducing them to such lower term or degree as may be desirable.

(2) A means for flexibly uniting a vibrating scale-beam either to a fixed abutment or to another beam of the same system, in such manner as absolutely to eliminate friction, and to preserve indefinitely the fulcrum intervals or distances precisely as first adjusted, and to resist and transmit all the pressures and shocks to which the fulcrums are subjected, without in the slightest degree impairing their sensitiveness or durability.

Hydraulic Chambers.—The hydraulic construction is such that through it the load or strain put on the specimen is transmitted without loss to a hydraulic chamber or "support," in which is confined a thin film of liquid, usually 0·015 inch in thickness, the plane of which is normal to the axis of the machine and to the direction of strain. The area of this film is such that the maximum strain applied to the specimen, and through it to the hydraulic support, shall not be more than can be borne with safety in its most exposed part by the thin diaphragm which seals the chamber. There may be several of these supporting chambers, as in the case of the Watertown machine, where the load is received upon four such supports; or there may be only one, as in the case of the machine now to be described. The pressure per square inch on the liquid within the hydraulic support is transmitted through a small copper tube, without loss from friction or otherwise, to a much smaller chamber or "reducer," containing a similar thin film of liquid. The acting area of the liquid in the reducer is less than that in the larger chamber or support, in the proportion in which the load on the specimen is desired to be reduced before it is received upon the beams in the scale-case where it is measured or weighed. In the present machine this reduction is as thirty to one. The maximum load of 300,000 lbs. on the large support is thus reduced to a maximum of 10,000 lbs. on the reducer; and this latter strain is all that is transmitted to the beams in the scale-case. The elastic resistance to bending of the sealing diaphragm in the hydraulic support causes a slight reduction of the pressure transmitted to the liquid under the sealing diaphragm of the

reducer. As the diaphragms however are of very thin sheet brass, usually not more than 0·005 inch thick, and as the maximum motion of the piston of the support is less than 0·001 inch while the free span of the diaphragm is 0·10 inch, this reduction in pressure is very slight, and is practically immaterial, for the reason that it is fully taken account of in the adjustment of the weighing mechanism.

Levers.—In the scale-case containing the weighing mechanism, the pressure transmitted from the reducer is received at one end of a system of levers, and is accurately measured by means of devices described later on. It is first received upon a single lever having a ratio of twenty to one, whereby one-twentieth of the pressure is transmitted to a second lever, from which is suspended a series of poise rods arranged to carry the balancing weights for weighing the load. This second lever, having a ratio of twenty-five to one, is also connected to a third lever or indicator bar, the arms of which are as forty to one. The motion of the point of the indicator bar is consequently 20,000 times that of the reducer piston, and therefore 600,000 times that of the piston in the main support, which is directly connected with the specimen under test. As the force required to move any one of the poise weights for showing a change of balance will vary directly as the square of the velocity of its movement, it follows that, since the poise weights move only one-fortieth as much as the indicator, their resistance to the movement required by the indicator for showing a change of balance is only 1–1600th part of what it would be, if, as in other scales, the same extent of movement had to be made by the very lever carrying the weights. A movement of one six-millionth of an inch at the specimen produces a motion at the indicator point of one-tenth of an inch, which is easily visible; and, being resisted by no friction, and having only so slight a resistance of inertia from he poise weights, the indicator shows clearly any slight or sudden change in the balance of the scale. It thus enables the exact point to be detected at which the load falls off slightly, as in the case of a tension specimen when a strain is reached which gives it a slight permanent set; the sudden change in the balance of the machine, shown by the vibration of the indicator, at once denotes the point at

which the limit of elasticity in the specimen is reached. This is due to the fact that a slight reduction in the strain always occurs at that point, owing to the sudden elongation of the specimen, which is practically instantaneous, while the movement of the straining press for taking up this slack requires a sensible length of time.

Fulcrum-plates.—Each of the supporting and connecting fulcrums in the system of levers consists of a thin plate of tempered steel, and acts absolutely without friction or back-lash. Each fulcrum-plate offers a slight elastic resistance to bending, but this resistance is recognised and fully balanced in the adjustment of the poise weights; in other words, if this and the other elastic resistances of the mechanism amounted to one-thousandth part of the load, the poise weights would then need to be one-thousandth part lighter than if the mechanism offered no such resistance. The poise rods which carry the balancing weights are also suspended by thin steel plates, which give no frictional resistance. In common scales there is unavoidably a large frictional resistance, whereby more or less of the pressure transmitted by the load is absorbed, and thus fails to reach the balancing weights. This defect is magnified by the tendency of the frictional resistance, first to hold the balancing bar from moving forward until the pressure has accumulated somewhat; and then, after it has moved forward under this impulse and has been carried too far, to hold it in that advanced position and not allow it to recede and come to rest at the true point corresponding with the load. The Emery system of construction is such that none of these frictional resistances occur. Certain elastic resistances are developed at various points, but these are all duly considered in adjusting the poise weights as above stated. The distinction may be briefly stated thus: frictional resistance and elastic resistance both absorb power, but the former absorbs it finally, whereas the latter simply stores it up and subsequently gives back whatever power or impulse it has received. This difference is one of great importance in any mechanism for weighing.

The thickness of the fulcrum-plates varies from 0·004 to 0·06 inch. When they are 0·01 inch thick or more, they are used in compression; but when of less thickness they are usually employed in tension. When used in compression, they are held by being

forced, under pressures generally of 60,000 to 120,000 lbs. per square inch of section, into grooves planed or sawn in the pieces they are to unite; when used in tension, they are generally clamped in position. The maximum working strains on the fulcrum-plates, whether in tension or in compression, are usually limited to 50,000 lbs. per square inch. The exposed or free portion of each fulcrum-plate varies in length from 0·1 to 0·2 inch, this being the interval separating the two parts that are connected by the plate. The angular motion of the lever causes a bending of the fulcrum-plate which carries it, but this bending is very minute, except only in the case of the fulcrum-plates carrying the last lever or indicator, and these are thin and long. The resistance of the fulcrum-plates to bending is very considerable, but is always well within the elastic limit of the material: so that their resistance is entirely elastic, and not frictional, and is provided for as above explained.

The above devices, whereby pressures of high intensity are received, transmitted, rendered visible and measured, are made available for their intended purposes by means of other details, equally novel and important, whereby the parts that receive and transmit the load are securely held against displacement or derangement in any direction, save only one which is parallel to the true line or axis of strain: in which direction they are left entirely free to move, without friction of any kind, and without any resistances except such as are taken account of in the total resistance of the weighing mechanism.

Figs. 1 and 2, Plates 32 and 33, are two general views of the machine, Fig. 1 being a front elevation, and Fig. 2 a side elevation of the testing machine proper. In Fig. 3 is shown a plan or top view of the straining mechanism.

In Figs. 14 and 15, Plate 37, is illustrated the scale case, containing the mechanism for measuring and indicating the strains on the specimen, and the valves for controlling the action of the machine. Fig. 14 is a plan, and Fig. 15 a front elevation of the scale case.

In Plates 34 to 36 are illustrated various details, some drawn double full size.

Figs. 20 to 30, Plates 39 to 41, show the construction of the holders for tension and compression, and the apparatus for transverse tests.

Hydraulic Chambers.—The testing machine proper, shown in Plates 32 and 33, comprises the apparatus for holding and straining the specimen to be tested. The bed or base of the machine, as shown more clearly in Fig. 6, Plate 34, consists of a hollow rectangular frame F of cast iron, having two rigid bearing surfaces, one near the bottom and the other at the top, suitably united at their four corners, and thus leaving an interior open space. Rising from the bed, as seen in Figs. 1 and 2, are the two main adjusting screws M, carrying the hydraulic straining press P, the vertical adjustment of which is effected by means of the long nuts N, Fig. 4. The nuts are geared together, and are rotated equally by means of a vertical shaft and bevel gearing worked by a handle or belt pulley at X, Figs. 1 and 2. The fluid pressure is conveyed to the ram through the jointed tubes T. The hydraulic press acts in one direction for tension, and in the reverse direction for compression and transverse strain; in either case its pressure is directly transmitted to the specimen A. The upper holder U for holding the specimen is attached direct to the ram of the straining press; the lower holder L is secured to the head block H, which in turn is connected by four steel bolts to the bottom block B, as shown in Fig. 5, Plate 34; these two blocks thus constitute a yoke or stirrup, which envelopes the hydraulic chamber or support S. This yoke is secured in proper position within the frame F by horizontal fixing plates I of thin tempered steel, which hold it steady laterally, while leaving it free to move vertically through the minute range desired. The transverse beams GG pass between the yoke blocks H and B, and bear at their outer ends against the cross beams of the frame F. These transverse beams are similarly free to move vertically within slight limits, but are stayed against all lateral motion by flexible fixing rods J, Fig. 1. Between the transverse beams GG is the hydraulic chamber or support S, which is 24 inches in diameter, and 3 inches in axial length. The space between the blocks H and B is 0·007 inch more than the thickness of the parts contained between them; and this clearance is transferred from the upper to the lower block,

according to the direction in which the specimen is strained. The change is conveniently effected by a single turn of a pair of nuts above the caps of the load springs R, Figs. 26 and 28, Plate 41. The function of these initial load springs is also to take up and absorb all clearance or back-lash; in changing the apparatus from tension to compression, the clearance or back-lash is taken up in the right direction by the load springs, and the scale is then balanced with the parts in this position before commencing a test. The strain received by the specimen from the straining press P is directly transmitted through the yoke and beams G G to the hydraulic support S. No frictional resistance is developed under the action of the load; but a slight elastic resistance is developed in the fixing and stay plates, by the minute yielding of the parts under pressure. This resistance however is not lost or absorbed, but is all of it taken account of in the rating of the scale. The strains resulting from tests of compression or tension act identically except in direction, the former acting downward on the support, and the latter upward.

The hydraulic support, shown in Figs. 8 and 9, Plate 35, consists essentially of a base-block K, 24 inches diameter, to which is bolted a ring N, and within the latter is a movable disc or piston D. The lining diaphragm of the base-block and the working diaphragm of the piston are each made of soft sheet brass 0·005 inch thick; and each as originally made is flat and smooth. These parts are put together as shown half full size in Fig. 10 and double full size in Fig. 11, Plate 36; and as soon as the fluid pressure is introduced between the two diaphragms, it forces the thin brass into the annular grooves turned in the base and piston, Fig. 8, thus interlocking each diaphragm with its rigid backing, and relieving it from all looseness or tendency to buckle under changes of temperature. The diaphragms thus act simply as linings to prevent the escape of the contained fluid. An interval of 0·1 inch is allowed between the piston D and the ring N, Fig. 11, and through this interval all round the piston the diaphragm is unsupported. The piston is thus permitted to move vertically, the exposed portion of the diaphragm acting as a flexible joint or hinge. The motion of the piston however, being due chiefly to the compression

of the liquid and its contained air, is limited to a maximum of less than 0·001 inch. While thus left free to move vertically within these minute limits, the piston is secured against all lateral motion by the annular fixing diaphragm V at its upper face, and the working diaphragm at its lower face, Fig. 11.

The smaller hydraulic chamber or "reducer" R, contained in the scale case, is shown half full size in Fig. 12, Plate 36. It consists of a steel base-block and ring, with the pressure diaphragm resting on a movable disc or piston. In this case the brass lining diaphragm is dispensed with, and a single diaphragm of tempered steel is employed, which is best shown in Fig. 13, double full size, and consists of a flat disc of spring steel tempered, 0·006 inch in thickness. It is sealed by bedding against a lead ring contained between two bronze rings, the fluid being retained between the upper side of the diaphragm and the under surface of the steel base-block. The annular space between the piston D and the ring N is 0·06 inch, which is the amount of free span of the diaphragm to permit of the free vertical movement of the piston under pressure. An annular fixing diaphragm V is used to centre and guide the piston, in the same manner as in the case of the larger hydraulic chamber or support.

In Fig. 31, Plate 42, is shown the form of hydraulic support used in railway weighing machines, which clearly illustrates the construction and action of this important element of Emery's system. The cap C is placed over the support to exclude dirt, and the platform of the scale rests on this cap, the pressure being transmitted by it through a block of rubber R to the head of the pressure column P. The pressure thus received is supported on the thin film of fluid contained between the bottom of the column P and the base piece B, this pressure being communicated through a small copper tube to the scale mechanism by which it is weighed.

The fluid employed for filling the hydraulic supports and chambers is either refined kerosene oil, or alcohol and glycerine. No waste of this fluid occurs in use, either from leakage or evaporation, all of the joints in the hydraulic support and reducer, and the connecting tube between them, being made absolutely tight without packings.

Scale case and Levers.—The hydraulic portion of the weighing mechanism terminates at the reducing chamber. In Figs. 15 and 17, Plates 37 and 38, the reducer R is seen in position in the scale case. The pressure of the liquid in the reducer, tending to separate the piston and the fixed base-block, acts against the frame A above as an abutment, and is received upon the transverse block B below, which in turn transmits it through the first steel fulcrum-plate to the first or main lever M. This fulcrum-plate carries about 10,000 lbs., being 1–30th of the load put upon the hydraulic support in the testing machine. As shown double full size in Figs. 18 and 19 it consists of a thin piece of tempered steel, 0·06 inch thick by 0·3 inch long and 10 inches wide, forced under the heavy pressure of 40,000 or 50,000 lbs. into seats in the two pieces which it connects; the interval between the two pieces is 0·15 inch, which is the width of the free or exposed portion of the fulcrum-plate. The relation and arrangement of the several beams composing the lever system of the scale are shown also in Figs. 16 and 17. The right-hand end of the first lever M is connected with the fixed frame of the scale case by a similar fulcrum-plate, so that the downward pressure from the reducer received through the block B tends to depress the left-hand end of the first lever M. At the left-hand end this lever is connected by another smaller fulcrum-plate to a vertical link L, contained in a recess of the scale frame and extending upwards through the latter, its head being seen again close to the indicator scale in the upper part of the case. The action of the reducer thus causes downward pressure on the link L, the upper end of which is connected by a thin fulcrum-plate, 4 inches wide by 0·02 inch thick, to the overhanging short arm of the second lever S; the fulcrum supporting the latter is slightly to the right of the connection with the link L, and consists, as in the previous case, of a flat steel fulcrum-plate, one edge of which is fixed in the under side of the lever S, and the other edge in an abutment of the scale frame. The pressure transmitted from the reducer thus tends to depress the left-hand end of the second lever S, and to elevate proportionately its right-hand end. The third and last lever consists of the indicator bar I, which is suspended at its right-

hand end from the scale frame by two thin fulcrum-plates, set 4 inches apart, each of them being 0·005 inch thick by 0·3 inch long and here used in tension; whereas all the fulcrums previously described are used under compression only. In like manner, the right-hand end of the indicator bar I is connected with the second lever S by a thin fulcrum-plate which is also always in tension, owing to the fact that the indicator bar, aided by the small sliding weight W which it carries, over-balances by reason of its great leverage the combined unbalanced weight of the levers M and S, of the vertical link L, and of their connected parts. The balancing of all of these movable parts, and the adjustment of the scale so that the indicator stands exactly at the zero point when the machine is unloaded, are effected by sliding the balance weight W along the indicator bar to the proper position, and there fixing it by a thumb-screw in the weight. The sensitising weight E, on the right-hand overhanging end of the indicator bar, is capable of vertical adjustment, the effect of which is to alter the centre of gravity of the indicator bar relatively to its point of suspension, and thus to change the sensitiveness of the scale. Usually this weight is so adjusted that the point of the indicator bar shall move one division on its scale for each ten pounds of load applied to the specimen. The amount of vibration of the indicator over its scale thus affords a most convenient means of reading small variations in the load.

As already explained, the total multiplication of the lever system is 1 to 20,000. This enormous velocity ratio is made possible, without the great loss inherent in the knife-edge system from friction and from change in fulcrum distances, by the use of the system of plate fulcrums, whereby the two fulcrums which determine the length of the short arm of each lever can properly be brought into close proximity, and the leverage in each case made proportionately large. As each succeeding leverage is multiplied by that preceding it, the total becomes rapidly very great. Hence a very small weight on the indicator bar counterbalances a very large force acting through the reducer on the first lever. Conversely it follows that the amount of motion of the indicator bar sufficient to be distinctly visible, say 0·1 inch, is reduced, through the action of the lever system,

to 1–20,000th part, that is 1–200,000th of an inch, at the transverse block B, Fig. 17, which bears against the reducing chamber R; this is therefore the motion of the piston of the reducing chamber, while 1–6,000,000th of an inch is the corresponding motion of the piston of the hydraulic support in the testing machine. The motion of the latter piston, and of the flexible diaphragm on which it rests, thus becomes exceedingly minute, and insensible to sight or touch. This fact should be borne in mind in considering the motion in both the hydraulic chambers, in each of which it is so extremely minute that their functions can be more appropriately described as consisting simply in the reception and transmission of pressures of varying intensity, rather than in motion of one part relatively to the other.

Referring again to Plate 37, it will be seen that each increase of pressure applied to the specimen tends to depress the left-hand end of the first lever M, and therefore to depress similarly the point of the indicator bar I. Downward motion of the indicator therefore denotes increase of load and the need of additional weights to balance it, while upward motion of the indicator denotes a reduction of the load or an excess of counterpoise. The operator thus quickly learns that if the point of the indicator falls below the zero mark he must apply more counterpoise, and when it rises above the zero mark he must decrease the counterpoise. There are four series of counterpoise weights, each series controlled respectively by one of the four handles H, through a set of levers connecting these handles with the frames which carry the weights when they are not required on the poise rods of the beam. Briefly described, each of the successive series of weights is in the ratio of ten to one; each series except the last comprises nine individual weights, of which any desired number can be instantly applied to or taken off from the poise rods of the scale beam by a simple motion of the handles. The operator uses only two of these handles at a time, watching the indicator bar and keeping the scale beam balanced within limits less than its full vibration; and by noting the pointers carried by the four vertical rods connected with the handles H, he has always before him a clear indication of the position of the whole series of poise weights. This record remains undisturbed by the

breaking of a specimen, and can be accurately noted afterwards. In accurate work the position of the indicator bar at the moment of rupture should also be noted, and the load it indicates should be added or subtracted before the load indicated by the poise weights is recorded.

The strains upon the specimens are controlled by valves contained in the lower part of the scale case, Plate 37, and worked by hand-wheels which are conveniently grouped together to the right of the handles H that control the poise weights. The hand-wheel V controls the main inlet valve between the pump or accumulator and the testing machine; and the smaller hand-wheel on the top of it controls a smaller and finely graduated valve contained within the main valve, thus affording convenience for all possible adjustments of flow; the rate of motion of the ram can be adjusted to a maximum of one foot per minute, or to a minimum as small as 0·001 inch in half an hour. The handle D controls a set of reversing valves, which determine the direction of flow from the pump or accumulator into the hydraulic cylinder or straining press of the testing machine. When standing in the position shown in Plate 37, these valves cause the liquid from the pump or accumulator to flow to the underside of the piston, thus moving it upward, as required in tests of tension; turning the handle D to its other position, that is through an angle of 180°, reverses the direction of flow, and causes the piston to descend, as required in tests of compression. A single motion therefore of the handle D enables the operator to reverse and entirely control the direction of motion of the piston or ram of the straining press, whether for the purpose of adjusting it for making a test or for the actual making of the test itself. The two handles F control a by-pass or circulating valve, the opening of which lets off the pressure in the straining cylinder to any desired extent, by permitting the escape of liquid therefrom into the reservoir or cistern.

All the weighing mechanism contained in the scale case is protected from dust, and from currents of air, by a plate-glass sash in front, Plate 37. In addition to this, a shutter of wood can be let down over the sash, which, meeting a similar folding

shutter in the lower part of the case, entirely closes and protects the weighing mechanism and valve gear. This shutter being secured by a lock and key, the machine is safe from interference or injury. The only connections between the scale case and the testing machine proper consist of the small copper tube connecting the hydraulic support with the reducer, and of the pipe connections between the valves in the scale case and the jointed pipes T on the testing machine, Plate 32. The scale case can therefore be placed in any desired position relatively to the testing machine, and is disconnected from the latter so far as relates to transmission of shock or jar resulting from the rupture of specimens. The elimination of all back-lash, and the careful provision for the absorption of all shock and recoil, combine to reduce the effect of the rupture of specimens to a minimum which is so surprisingly small as to be hardly credible until actually seen. An observer may safely keep his hand on the platen of the testing machine while a specimen of the largest size is tested to rupture, no sensible jar being experienced even at the instant of rupture. Indeed, except for the pistol-like report caused by the sudden rupture of a large specimen, particularly of metal having a high modulus of elasticity, such as steel with a high percentage of carbon, the senses would hardly take cognizance of the fact that rupture had occurred.

Holding of Specimens.—In Figs. 20 to 22, Plate 39, is shown the apparatus for holding specimens in tests for tension. Each of the tension holders consists of a cylindrical steel shell H, properly secured to the platen of the machine and to the ram M of the straining cylinder. The outer end of this shell, as seen in Fig. 21, has conical seats bored within it, in which are two cylindrical wedges D. Suitable jaws or clamps are fitted to the internal faces of these cylindrical wedges, for adapting them to receive round, square, or flat specimens of the various commercial sizes. The jaws having been opened sufficiently to admit the specimen are again closed upon it, thus giving a slight initial grip, after which the motion of the straining press in applying strains to the specimen causes the cylindrical wedges to be drawn outward in the shell of the holder,

thus forcing them still more tightly upon the specimen by reason of the incline or wedge form of the cavity within which they slide. Two transverse following wedges W are provided, which, under the pressure of spiral springs coiled in the two spring boxes R on each side of the holder and acting through cords, tend to close together, and thus follow up the gripping wedges, as the latter move outward under the action of the increasing strain upon the specimen. The result is that when rupture takes place little or no back-lash is possible in the holders, each of which acts substantially as a solid block in transmitting the shock to the parts which, as already stated, are so constructed as to receive and absorb it without injury.

In Figs. 23 to 25, Plate 40, is shown the arrangement of platforms used in making tests under compression. Fig. 25 is a sectional view of the compression platform as applied to the bottom of the ram M of the straining press. Upon the end of the ram is screwed a nut or sleeve, which in turn carries and supports the bed B. This bed has a convex spherical surface, against which is fitted the head or platen P, having a corresponding concave spherical surface. The latter piece is provided with six adjusting screws, by means of which it can be revolved or shifted relatively to the convex bed, so as to cause the outer face of the platen P to take any desired angle relatively to the axis of the machine or specimen. The adjustable platforms make it unnecessary to observe any special care in securing parallelism between the ends of a specimen to be tested under compression. All that is needed is that each end should be a true plane; and if these two planes are not exactly parallel, either or both of the adjustable platforms is so adjusted that the plane of its bearing face coincides with that of the end of the specimen, Fig. 23, while the axis of the specimen remains parallel with that of the machine. This being done, the test can be proceeded with under assurance that the results obtained will be exactly the same as though the ends of the specimen were not only true planes, but were also exactly parallel. The facility thus afforded tends not only to more correct results in testing, but to great economy and convenience in the preparation of specimens. When it is desired, the face of the

platen P can be set normal to the axis of the machine, in which position it is shown in Fig. 25.

The apparatus for transverse tests is shown in Figs. 26 to 28, Plate 41. A heavy rectangular bar G of steel is placed upon the platen of the machine, and suitably secured there. Its outer ends are supported by inclined struts T, the lower ends of which are stepped into the foot block B of the stirrup or yoke shown in Fig. 5. Downward pressure on the bar G acts therefore upon the testing machine precisely as similar pressure transmitted through a specimen when tested in compression. Sliding on the top of the bar are two supports or bearings S, on which rests the specimen A. These bearings may be set at any desired distance apart, according to the length of the span desired for making the test. Their positions are accurately indicated by the scale engraved on the side of the bar G. A smaller but similar apparatus is shown in Figs. 29 and 30, designed for transverse tests of short specimens only. This is identical with the larger apparatus, except that the bearing blocks are moved and set by a right-and-left-hand screw worked by a crank handle. An ordinate bar is suspended within these bearing blocks, in such a manner as to be entirely free from distortion during the progress of a test, thus affording a true base-line from which, by means of the sliding gauge D shown in Fig. 30, the deflections of the specimen can be accurately measured.

Rating.—The mode of rating the action of Emery's testing machine with standard dead weights is as follows. The internal diameter of the larger hydraulic chamber when completed can be accurately measured with the greatest precision. The exact diameter of the reducer, and the ratio between the two hydraulic chambers, are not material, and practically are never considered, except approximately when designing the machine. In like manner, the fulcrum distances of the levers are originally fixed approximately, but in actual construction are never gauged or in any way closely determined in the adjustment and rating of the scale. The aggregate velocity ratio between the platform movement and the movement of each poise weight is determined by actual loads

simultaneously placed on each and balanced. The loads applied to the platform are obtained from a special rating machine, the action of which has been carefully determined at each point with actual dead loads, so that its indications are known to be correct. By means of this rating machine, known loads are applied to the hydraulic support of each testing machine, up to its maximum capacity. The exact weight required on each poise rod to balance a known load on the machine is thus ascertained by actual test, and the poise weights are then carefully adjusted thereto. Each of these weights is electro-plated with gold to protect it from oxidation, and all are contained in a dust-tight case behind plate-glass; in use they are applied without friction, and without being touched by the hand. The ratio between the two hydraulic chambers remains absolutely without change; and in like manner the fulcrum distances of the lever system are unchangeable. Inasmuch therefore as the aggregate ratio between the larger hydraulic chamber which receives the load and the weights by which the intensity of the load is measured, is thus readily determined by actual test throughout the entire range of the machine, and as this ratio remains constant, it follows that the machine when once adjusted and rated will continue unchanged indefinitely; and this conclusion is confirmed by actual experience. In machines based upon the principle of the common knife-edge scale, on the contrary, the test with known dead loads usually covers only a small portion of the range of the machine; and it is assumed that the action of the machine throughout the remainder or higher part of its range will be the same proportionately as within the lower range tested by actual loads. This assumption is undoubtedly erroneous; for experience has shown that absolute or even approximate rigidity in such machines is impossible, and that the yielding and bending of the parts of a knife-edge scale inevitably cause serious disturbances in the fulcrum distances and also in the frictional resistances, while for neither of these disturbances does the knife-edge system provide any compensation. Extensive experience has established the fact that the principles involved in the construction of Emery's machines, and the methods adopted in

adjusting them, are such that a degree of precision has been attained beyond anything previously accomplished, and that this precision is maintained unimpaired even under the exceptionally severe conditions obtaining in the use of testing machines of large capacities.

As indicative of unsuspected sources of error in the earlier and cruder testing machines, particularly those in which the applied strains are measured by simply gauging the hydraulic pressure in the straining cylinder, it may be mentioned that a test was recently made of one of the largest machines of that kind in the United States, by having a large and long bar of steel tested for extension in the Watertown machine, the test being carefully kept within the elastic limits of the metal, and the stretch accurately noted by micrometer gauges at each successive increment of the load. The specimen being released from strain was found to return to its original form, thus showing conclusively that it had not been strained up to its elastic limit. The same specimen was then subjected to test in the hydraulic machine above mentioned, and its extensions were again noted by micrometer gauges, the specimen thus serving as a delicate dynamometer by which to determine the differences in the readings of the two machines. With loadings up to a maximum of 400,000 lbs. these differences, under precisely equal extensions of the specimen, varied from 4 per cent. to 16 per cent. of the applied loads, the larger proportional discrepancies occurring with the smallest loads. These results are corroborated by other experiments which have been made with the Watertown machine, and justify the assertion that in ordinary testing machines the rate of error or variation, due to loss from friction and to incorrect methods of weighing, covers a wide range, amounting in some cases to probably more than 20 per cent., and rarely, if ever, to less than 5 per cent. in the case of hydraulic machines. For certain commercial purposes this approximation to facts may suffice; but for the more accurate purposes of scientific work, as well as for ultimate economy and safety even in ordinary commercial work, testing machines of greater accuracy will inevitably be required. The appliances now described meet these requirements in the fullest

degree; they have been extended in practice to machines ranging in capacity from 70,000 to 800,000 lbs., and are capable of advantageous application to machines of any desired capacity, the designs for a machine of 1,200,000 lbs. capacity having already been prepared.

From the foregoing description the writer hopes it will be seen that the inventions of Mr. Emery have led to the production of a machine capable of developing and controlling forces amounting to hundreds of tons, and of so utilising and weighing these forces as to entitle the machine to take rank as a true instrument of precision. This machine, it is believed, is the first in which all of the factors of the case have been successfully provided for, so that all sources of error and doubt are eliminated, and results are made possible which in the fullest sense are precise and accurate. These important results are obtained by a degree of precision and perfection heretofore rarely if ever attained, or even attempted, in mechanism of such large dimensions. At the same time unusual facility has been obtained for the convenient manipulation of specimens, and for the adaptation of the machine to the different kinds of tests.

Discussion.

Mr. Towne wrote expressing his disappointment that he had found it impossible to get the testing machine erected in readiness for the present meeting. It would however be ready for exhibition in London in the course of next month and afterwards; and the Members were cordially invited to inspect it, and also to send or bring with them any specimens which they would like to have tested by it. At the proper time this invitation would be extended to the engineering profession generally throughout England.

Mr. Benjamin Walker, Member of Council, said the main element of difference between this machine and the lever testing machine was that, instead of having a lever with a knife-edge bearing, which if mathematically constructed would accurately show the pressures at its opposite ends, the present machine depended upon the well-known law of uniform pressure of liquid. It was no doubt true that, if the hydraulic support was in its proper position below, and if there was no undue friction arising from the pistons, and if the weights on the levers in the scale case were all correctly applied and correctly recorded, and if everything else was in perfect order, a correct result would be obtained. But the lever machine appeared to him to be as accurate as this. Not having yet seen the new machine, it seemed to him at present to have elements of distortion which might lead to a misunderstanding of the specimen, just as was the case with the lever machine if it was not properly constructed or properly worked. Either of them when worked carefully would record exactly the extent of strain that had been put upon the specimen. A very heavy strain, such as 400 or 500 tons, could not readily be carried on knife-edges; and therefore the new machine might have an advantage for very large specimens. He had heard it suggested that a steel-maker, when he got to know what his steel could stand, could adapt the testing machine to suit it, and could contrive to record the experiment just as he would like to have it. Although he had never seen testing carried on in that way, and did not believe that it was so carried on, he must certainly admit that it was easy to make a testing machine record whatever was desired, if it was unfairly handled. But with fair handling it was possible to obtain as complete a knowledge as could be wished of the quality of the material tested.

Mr. Daniel Adamson, Vice-President, said he had not yet seen the machine, and it was an uncommon arrangement to himself, because in England dependence had hitherto been placed on knife-edges, when great accuracy was wanted. In his limited experience with hydraulic gauging he had found it most unfortunate and erroneous. In a hydraulic machine of the best make at his

own works, in which the pressure was registered by two ordinary pressure-gauges, one of them got broken by accident, and was sent back to the manufacturer to be repaired. On its return it would not agree with its fellow gauge. It was sent back again, but was returned still erroneous. After a third trial the manufacturer asked to have both the gauges sent to him, in order that he might make them agree together. Notwithstanding the erroneous records obtained when the two gauges did not agree, yet he admitted that for many purposes the hydraulic gauging answered as a comparative testing machine, and would give results with reasonable despatch; only it was necessary to prepare specimens at a considerable cost, because the machine was not provided with any such ingenious means of attachment as was furnished by the grip-boxes in the Emery machine. As a manufacturer of testing machines he had always found that the grip-boxes were a difficult portion of the apparatus. It was certainly not so while testing elastic material and material that would stretch a great deal; but when testing hard cast-iron, which did not yield through its own elasticity except to a very minute extent, if the grip-boxes did not get fairly hold of the specimen it gave way long before the full load came upon it. In such a case it did appear that there was some advantage in using the grip-box of the Emery machine in order to get a truly parallel pull, so that the specimen should be uniformly strained across its whole section as the load came upon it.

As a manufacturer of special testing machines he had adopted multiple levers, because he was convinced from experience that levers having a very short arm to carry the load were very difficult to get accurate. Where the load was a considerable distance from the fulcrum—not less than six inches—and the lever multiplied ten times, its accuracy was verified either by observing the extent of vibration at the ends of the arms to be as ten to one, or by balancing dead weights in the proportion of ten to one, or else by measurement of the length of the arms in the same proportion. If such a lever was repeated four times over, an equally accurate multiplication of 10,000 times would be obtained in comparison with the 20,000 times given by the levers in the scale case of the Emery

(Mr. Daniel Adamson.)
machine; and a motion of 1–10th of an inch at the free extremity of the last or registering lever would represent 1–100,000th of an inch in the specimen under test. This he considered a sufficiently minute result; but a skilled observer could go still further, and detect a movement even as small as 1–100th of an inch at the end of the lever, corresponding with only 1–1,000,000th of an inch at the specimen, which was almost beyond what imagination could reach. That was the system he had worked with, and many other engineers in this country had worked with it also; whether there were four levers, or less or more, the principle was the same. To secure a highly refined and accurate record, the multiple-lever system with high magnifying power was indispensable. He could not imagine that a much more elaborate testing machine was wanted, unless, as Mr. Walker had suggested, it was desired to deal with specimens of much larger size. In that case it might be desirable to have a national testing machine capable of taking specimens of 5 or 6 inches diameter, in order to see whether the endurance of the metal was equal in the larger bar to what it was in the smaller. For his own part however he had always objected, when an accurate record was wanted, to deal with a specimen exceeding half a square inch in sectional area. That was the size he believed which Sir Joseph Whitworth had depended upon in testing by hydraulic power the quality of the metal for his guns. If a bar of larger area were tested, the strain could not in his opinion be transmitted equally right through to the centre. The grip-boxes seized the specimen by the outside, and dragged the outside sooner than the inside; and before the final rupture took place in a large bar it would begin to contract towards the breaking area, so that the specimen would all the while be really carrying less and less down to the moment of rupture, breaking as it were piecemeal or step by step. In a very hard material there was of course little or no elongation; the renowned ship-plates of old times broke transversely without elongation, and were always treacherous. But with the modern and more reliable metals the outside stretched greatly, and while that was taking place the weight came gradually down and down, and the specimen broke

with a much reduced area, and with a load much below its maximum carrying power, which would have been previously registered.

Mr. W. H. Stanger said it certainly seemed to him that this was a machine magnificently and splendidly devised with cunning skill to overcome what did not exist, namely friction of an appreciable amount on a knife-edge. Anyone who took the trouble to study thoroughly a machine which worked on knife-edges, such as the Wicksteed 50-ton testing machine which he was himself using, would find that even with heavy loads there was practically no friction whatever on the knife-edge. So simple a contrivance as a single lever carried on a knife-edge, as in the Wicksteed machine, could not in his opinion be improved upon either by a complication of levers, or by doing away with the knife-edge. The fulcrum-plates, which were substituted for knife-edges in the Emery machine, must in themselves have a certain amount of resistance, however minute, because no piece of metal could be bent without offering a certain amount of resistance; and in the conditions under which the fulcrum-plates were working they must inevitably deflect more or less. Was it necessary to improve upon a machine which possessed only two knife-edges, while in those knife-edges the alterations due to the weight upon them were practically *nil*? He failed to see how such a machine could be improved upon in regard to getting rid of friction. He also failed to see how three levers were better than two; or how twenty weights were better than one. Being himself very much interested in the matter, he was looking forwards to the promised opportunity for seeing the machine itself in a more connected form than that in which it could be represented by drawings alone.

The President asked what amount of force was required to make the lever move in the Wicksteed machine when there was a pull on it; and whether the Members could see the machine used by Mr. Stanger.

Mr. Stanger replied that with 50 tons on the short arm of the lever, and an equivalent load at the other end, the pressure exerted

(Mr. W. H. Stanger.)]
by one finger on the heavier weight was sufficient to move the lever up and down. A very small weight added or removed at the short arm would bring the long arm of the lever with a thump against the spring stops, with practically no friction at all. He should be very happy to show the Members the Wicksteed machine at his works in Westminster whenever they pleased.

Professor Archibald Barr was of opinion that the details of the Emery machine were admirably designed; and from his own limited knowledge of American work he had no doubt that the workmanship would be as good as the design. At the same time he thought that there was a very simple radical defect in the principle of the machine, namely that the multiplying power was much too great. The smaller the multiplying power, he considered, the better was the machine for purposes of accuracy. There was frequent reference in the paper to the *weighing* of the stress upon the specimen; and it seemed to him that a good deal of misconception might arise through the use of that expression. As a weighing machine indeed he thought nothing could be superior to the Emery machine: if a dead weight were put upon the platform he had no doubt the machine would weigh it with a wonderful degree of accuracy. But he wanted to point out that in testing a specimen there was not a dead weight to be dealt with, but something quite different. In page 219 of the paper it was stated that the rate of motion of the ram could be adjusted to a maximum of one foot per minute, or to a minimum as small as one-thousandth of an inch in half an hour. If indeed the testing were done at the rate of one-thousandth of an inch in half an hour, he had no doubt it might be done with very great exactitude; but life was too short to conduct even scientific experiments at that rate, and certainly for commercial purposes the testing was required to be done at a much quicker speed. A specimen of mild steel, 10 inches long, would extend about 3 inches before fracture, as illustrated by the autographic diagram, Fig. 32, Plate 42. In ordinary commercial testing such a specimen would have to be tested in a very few minutes; but allowing nearly an hour for the test, the average rate of extension, that is the average

rate of motion of the straining press, would be about one-thousandth of an inch per second. Supposing that even such an exceedingly slow test were made in an Emery testing machine, and that the levers had no stability, one end of the specimen would be moved at the rate of one-thousandth of an inch per second; and if the poise-weight were allowed to remain constant for an instant the other end of the specimen ought to follow. The mechanism multiplied this motion 600,000 times; and hence the point of the indicator bar would have to start off with a velocity of 600 inches or 50 feet per second, and should therefore move from the centre to the end of its scale in something like 1-600th of a second. Such a machine would evidently be unworkable, even for carrying out in several hours the common test referred to, and for keeping the levers floating. The machine was rendered workable, partly by giving the lever system a very great amount of stability, namely 10 lbs. at the specimen for 1-10th of an inch of motion at the end of the indicator bar (page 217); but to a much larger extent he considered by the very great effect of the inertia of the poise-weights and levers, due to the great multiplying power adopted; and also by the resistance, due to inertia and friction, which was offered by the water in the small connecting tube between the two hydraulic chambers. With regard to the latter, the diameter of the diaphragm in the larger hydraulic chamber of the Emery machine appeared from the drawing (Plate 35) to be 22 inches, and that of the tube which conveyed the liquid to the reducer to be 0·08 inch: so that the area of the larger chamber would be about 75,000 times that of the tube. Therefore if there was a motion of one-thousandth of an inch per second at the lower end of the specimen, the water would be forced to go through that small tube at the rate of 75 inches per second. To start the water at anything like that velocity, and to overcome the friction in the tube, would require a considerable difference of pressure at the two ends of the tube; and this difference of pressure acting over the area of the 22-inch diaphragm would represent a very great stress on the specimen.

In page 210 of the paper there was a calculation which appeared to him to be exceedingly significant:—"As the force required to move any one of the poise weights for showing a change of balance will

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vary directly as the square of the velocity of its movement, it follows that, since the poise weights move only one-fortieth as much as the indicator, their resistance to the movement required by the indicator for showing a change of balance is only 1-1600th part of what it would be, if, as in other scales, the same extent of movement had to be made by the very lever carrying the weights." This argument seemed to him to be rather damaging to the principle of the machine; because it implied that, if the velocity of the poise-weights were further reduced 15,000 times—retaining the same motion at the indicator bar—the machine would then be 225 million times better in that respect than the machine described in the paper. The motion of the poise-weights could be reduced to that extent by applying the weight directly to the specimen; but as the ratio of multiplication of motion from the specimen to the poise-weights in the Emery machine was 1 to 15,000, the weight would then require to be 15,000 times as great; and hence, according to the argument quoted, such a machine would be $\frac{(15000)^2}{15000} = 15{,}000$ times better in respect to the inertia of the poise-weight than the machine described in the paper. In other words the passage quoted simply meant that a testing machine was good in proportion as the multiplying power was small, supposing the indicator-bar arrangement to be retained. It was no doubt a good point in the Emery machine or any other to multiply the motion of that end of the specimen to which the poise-weight was connected; but when that motion was multiplied up to 600,000 times, it became too quick to be observed at the rate at which the machine must work in practice, provided no resistance, in the form of stability, friction, or inertia, were interposed to retard the motion of the lever system. It might be said that, if this were so very great a defect, it would have been found out long before now in other machines of high multiplying power; but he wished to point out that the specimens which were mostly tested, and upon which the value of such a machine was usually judged, were specimens of a ductile character. On arriving at the climax C in the autographic diagram, Fig. 32, Plate 42, it would be seen that a further extension of the specimen did not require a further increase of the load. If therefore

when that point was reached the lever was in balance, it would remain for some time almost absolutely stationary, whether the inertia of the system was great or small in amount; and consequently the determination of the ultimate strength of a ductile material was not seriously affected by the inertia of the poise-weight and levers. If on the other hand in testing a non-ductile material the straining press were worked at anything like the same speed, he was satisfied that a machine of high multiplying power, such as that described, would not give such consistent results as would a machine of low multiplying power.

With regard to the fulcrum-plates, he considered that for a weighing machine the Emery machine was excellent, and that fulcrum-plates or other elastic connections would prove to be the right thing for balances. Chemical balances he believed might be made more delicate with fulcrum-plates than with knife-edges. But when all was admitted that could be said as to the imperfection of the knife-edge, he still thought there was no case against its use for a testing machine. In ordinary chemical balances working on knife-edges it was found easy to weigh to the 1–100,000th part of the weight in the scale-pan. When the size of the balance was increased to that of a testing machine, he believed there was no increased difficulty; therefore it should be possible to make a knife-edge machine, on any of the systems approved in this country, to record the 1–100,000th part of the load that the machine was dealing with. To test this conclusion he had made an experiment at Mr. Wicksteed's suggestion, by putting into the Wicksteed machine at the Yorkshire College, Leeds, a specimen of Lowmoor iron about 9 feet long, so that the extension of the specimen for any given increase of load should be as much as possible. By then placing different weights of small amount upon the shackle gripping the specimen, and also upon the long arm of the lever at an equal distance in front of the knife-edge, he had found that with a total pull of 43 tons upon the specimen he could tell by the motion of the lever without seeing when a 1-lb. weight was laid upon the shackle or lifted off it; and one pound in 43 tons was as nearly as possible 1-100,000th part. It should be remembered that the one pound could not swing the

(Professor Barr.)
lever as in a chemical balance, but it had to indicate itself by an alteration in the length of the specimen; and consequently the motion that was got at the end of the long arm of the lever could only be extremely small. If there were an actual dead weight of 43 tons hanging from the shackle on the short arm, he had no doubt the addition or removal of the one pound would cause a very sensible amount of motion at the end of the lever. As it was, the specimen had to be altered in length, and it was only the motion due to the alteration in length of the specimen, minus any retardation due to the knife-edge, that was represented by the motion of the lever; yet the extent of movement was quite sufficient to be read, as he should be glad to show to anyone who might be interested in witnessing the experiment. On the testing machine made by Mr. Wicksteed for the Yorkshire College laboratory he had got him to attach to the lever a vertical arm carrying an adjusting weight, so that the lever could be arranged in neutral equilibrium. This he considered to be a great improvement, because the lever now took almost no force to move it through its whole range.

Another point of interest was that in a testing machine with a moving poise-weight a continuous increase of load could be got, instead of the intermittent increase by the successive application of a number of separate weights. By the method adopted for applying the weights in the Emery machine he quite agreed that they could be applied with the utmost exactitude; but he thought it was well to be able to vary the load continuously during a test.

With regard to rating, it was stated in page 222 that the internal diameter of the larger hydraulic chamber when completed [could be measured with the greatest precision. He should be glad to know why that statement was made; because, if the machine was rated with dead-weights, then it did not matter at all what was the diameter of the chamber, inasmuch as this was taken into account in the rating.

Although the Emery machine did not seem to him to be one which offered facilities for the attachment of autographic indicators of various kinds, it would be exceedingly interesting if an autographic indicator—such as that used by Professor Kennedy (Proceedings

1886, page 65), where the stress was measured by the extension of an elastic bar or spring-piece, or else an autographic indicator in the form of Mr. Wicksteed's (Proceedings 1886, page 27)—were attached to it for testing its action upon specimens of different kinds. The indications of either instrument he was confident would be very erratic, if the test were made at any considerable speed in the Emery machine, and if the stress recorded were compared from point to point with the amount of the poise-weight.

At the conclusion of the paper (page 224) the only comparison attempted of the Emery machine was with a kind of testing machine which every engineer allowed was exceedingly bad. It was rather too late now for the merits of any machine—especially such an ingeniously designed machine as that described in the paper—to be compared with those of a machine which was universally condemned. If a comparison had been made with the most approved machines, it would have been much more satisfactory to mechanical engineers in this country.

Mr. Arthur Paget, Vice-President, referring to the remark (page 226) about the friction of pistons in the Emery machine, pointed out that the whole pith of this machine was that there was no friction of any pistons, but instead of that there was the bending movement of thin flexible diaphragms, which could not be called pistons. However novel the use of those diaphragms might be in testing machines, he would instance the corrugated-diaphragm aneroid barometer as an instrument acting on identically the same principle, with elastic thin diaphragms; two which he bought in Paris in 1855 had continued in action ever since without ever requiring any repairs, and were still registering with complete accuracy. Therefore an elastic diaphragm of that kind, though a novelty in a testing machine, was not exactly an untested novelty. It might be relied upon to work with a great deal of delicacy and accuracy; and he concluded there was no fear of friction when it was used to replace a piston in the machine now described. The main advantage of this machine appeared to him to lie in the use of water, which as compared with steel, iron, or any other metal, might

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be considered as inelastic. It was stated in the paper (page 220) that when the specimen broke there was practically no jar and no sign of disruption beyond the noise made by the breaking. Surely even in the best lever testing-machines it would be admitted that when the specimen broke there was somehow a strong reaction upon the machine itself, tending to injure it. The water did not spring in that way, and there was therefore not the same tendency to injury of the machine at the moment of the disruption of the specimen.

Mr. WILLIAM SCHÖNHEYDER did not understand how the Emery machine could be so infallible as it was represented to be. It was stated that friction had been eliminated; but something else had been introduced in its place, namely the elastic resistance of the diaphragms, and of the fulcrum-plates which superseded the knife-edges. He therefore did not see how the machine could in practice work to such a nicety as was stated. The thin film of liquid confined in the hydraulic chamber was stated in page 209 to be usually 15–1000ths of an inch in thickness, and the top and bottom of the chamber would accordingly be no more than that small distance apart. How could so small a distance be always maintained? When a heavy pressure say of 100 tons came upon the chamber, the pressure per square inch upon the contained liquid would be about 600 lbs., under which there must surely be some little extension in the tube, or some little spring in the free span of the diaphragm; hence he did not see how the film of liquid could be maintained in the chamber so as to prevent the top and bottom from sometimes touching each other. The maximum motion of the piston of the support was stated in page 210 to be less than one-thousandth of an inch, while the free span of the diaphragm was one-tenth of an inch; and he enquired whether that amount of motion was the result of calculation, or whether it had ever been actually measured. In a machine of this kind it appeared to him unavoidable that there must be a motion greater than only one-thousandth of an inch.

Mr. J. HARTLEY WICKSTEED, Member of Council, considered the Emery machine was so admirably worked out that it was worthy

of the fullest investigation. In regard to the rating, he enquired whether that had been done at different temperatures; because although the liquid was a very thin film, yet it expanded with heat so very much more than the cast-iron which surrounded it, that a plenum of pressure might be expected in the hydraulic support. This he surmised was provided for by the pair of load springs R, shown in Figs. 26 and 28, Plate 41, which were screwed up till they took up any slackness that there might be in the hydraulic chamber, and so brought the indicator bar to point to zero. Perhaps the resilience of those springs allowed for any contraction of the liquid in the hydraulic chamber, and perhaps also by screwing them up less tightly it allowed for any expansion of the liquid; but the only way in which this could be proved was by experiment, and he should be glad therefore to know as a matter of fact whether the machine had been rated over such a range of temperature as might be expected to be met with in practice. It would have been more satisfactory, he thought, if the machine had been rated with absolute loads. The statement in page 223 was that it had been rated by means of a rating machine. If the latter was itself another Emery machine of the same kind, it was simply carrying the proof round in a circle; no independent proof was obtained until the machine was referred to absolute loads. The rating machine had indeed been referred to absolute loads, but then it might be contended that there were elements in the rating machine capable of change from use, or from alteration of temperature or of load; and he considered that each individual machine ought to be proved with absolute loads. In proving lever and knife-edge machines it was stated that the proof with actual loads was never carried far, and was taken only by inference for the higher part of their range; that is, the verifying proof was made only with a small load, and it was inferred that a large load would prove the same. But that was not the case with knife-edge machines in this country in the hands of engineers who had very large interests at stake, and who might incur a serious loss by the rejection of a quantity of material which was a minute fraction below the designated strength. For the 50-ton single-lever testing machine at the Consett Iron Works, Durham, in order that there

(Mr. J. Hartley Wicksteed.)
might not be any doubt whether it was right or wrong, a large cradle had been constructed to hang on the back centre of the machine, and had been carefully balanced with a small weight on the end of the long arm. Then 56-lb. weights, recently adjusted at the weights and measures office under the charge of the weights and measures inspector, had been added in the cradle; and as every half ton of weights was added, the poise-weight was advanced along the long arm of the lever until the extremity of the arm came to equilibrium in its central position. Then a reading was taken as shown by the vernier. The result had been that throughout the whole length of the scale the readings had proved right to the second decimal place in fractions of a ton. The same trial had been repeated there every January for five years, and no re-adjustment of the knife-edges had been required. During those five years the machine had broken a quarter of a million specimens, while the Emery machine at Watertown was stated to have broken 15,000 specimens since 1879. The Consett machine tested the specimens so fast that it broke thirty in an hour, and with hard work three hundred in a day. The traction upon the specimen was at the rate of 3 inches a minute. If the traction were put upon a specimen in the Emery machine at the rate of 2 inches a minute, and if the pull was not exactly counterbalanced continuously by the levers, the end of the indicator bar would move, or try to move, at the rate of nearly 20 miles a minute. It could not move at that rate suddenly; and therefore there would be a pull upon the specimen which would be unrecorded by the number of poise-weights that had been hung upon the scale-rods.

To his mind the great practical difficulty with the machine was that the observer could not see when it was floating free. There was only a space of 15–1000ths of an inch in the hydraulic support in the direction of motion; and wherever the machine might be placed he supposed it would have to encounter rust and dirt or other obstructions which might choke that small space, and then the testing of the specimen might be going on without the observer having any indication of what was really being done upon it. In the lever machine, if the stress was unbalanced, it

could drag the back centre through a considerable distance, and what could be plainly seen was whether or not the lever was up against the top stop or down upon the bottom. If it was not, the lever was floating, and the specimen was supporting neither more nor less than what was represented by the position of the poise-weight upon the lever. It was a great advantage to be able to see this with one's own eyes; because if a large specimen was put into the Emery machine and gave an unexpected result, it seemed to him that the test was too much in the hands of a clever operator, who must be very practised and skilled in catching, with that system of poise-weights in the scale-case, the balance of the stress as rapidly as it accrued, because it was constantly varying.

One practical objection that he had to the machine in the matter of construction was its want of stability. It was clear that, the top of the machine being supported only by the two adjusting screws MM in Plates 32 and 33, if it were put to compress a specimen something like what was shown in Fig. 23, Plate 40, as soon as the specimen began to buckle in compression the top part of the machine would be strained out of alignment. In testing a specimen in compression it was requisite to have the top and bottom so well supported that they could not deviate sideways. The tops of those screws seemed to him to be insufficiently supported, and would have to be supported in some better way than was shown.

Mr. John G. Mair had seen the Watertown machine, and had witnessed the testing of a specimen by it. It was an exceedingly fine machine; and to judge by the broken specimens he saw, he should say that it had tested far more than the fifteen thousand mentioned in the paper. During the testing of a specimen in the machine he had pressed with his hand on the movable disc or piston of the hydraulic support, and the amount of this small pressure had been immediately recorded by the indicator. The specimen undergoing test was perhaps about 2 inches diameter, and the pressure he applied by hand could not have been more than 8 or 9 lbs. Its instant registration therefore showed the machine to be a very delicate one.

Professor W. CAWTHORNE UNWIN considered the paper was one of remarkable interest; and as it came from abroad, and its author was not otherwise represented at this meeting, he should be glad, having himself seen the machine, to endeavour to remove any misconception that might have arisen in regard to its action. Five or six years ago he had to select a testing machine for Coopers Hill College; and he was then satisfied that the Watertown machine was the most accurate machine in the world. At that time however the makers were not in a position to supply a small Emery machine; and he had therefore been obliged to put up with a Wicksteed machine. Subsequently a second Wicksteed machine had been made for him; and in these machines he had had the advantage to a great extent of having his own ideas carried out. Having used these two machines nearly every day for the past five or six years with an interest almost paternal, he not only knew how well they did their work, but had also found that they had some defects. About six months ago, on learning that there was an Emery machine in Paris, he went there for the sole purpose of seeing it, believing beforehand that it was a very delicate, sensitive, and accurate machine; but he had no conception until he saw it that his belief would be so thoroughly confirmed. The Emery testing machine was merely the illustration of a principle, of which other applications were probably much more important commercially than its application to a testing machine, although the latter was a good illustration of the principle. On the occasion of his visit, a bar of soft steel was put in the Emery machine, and a steam pump was started at a certain rate and was kept going continuously. During the whole time an observer stood at the scale case, holding two of the handles, one of which belonged to one series of poise-weights, and the other to another. During the whole testing of the specimen the indicator bar could be kept floating free of the stops; it was always just in motion, indicating with extreme rapidity and sensitiveness every change of stress. For the whole range of four inches of the indicator bar the whole corresponding motion at one end of the test bar was 1–80,000th of an inch. The adjustment of the weights was very simple; a motion of only three or four inches in the handle was sufficient to put the whole range of the weights on,

and by this means the indicator bar could be kept floating throughout the whole test. It was thus a continuous test; and even with the continuous movement of the rolling weight in the Wicksteed machine the stress could not be balanced better than it had been in this instance. But as a matter of fact every observation which was of the slightest value in testing was a statical observation, and he did not care for any testing observation which was not a statical observation; it was simply a matter of weighing, and he believed it had been admitted that as a weighing machine the Emery machine was perfect. The Wicksteed machine did its work perfectly well up to and beyond any limit of accuracy absolutely required in commercial work; but he had now convinced himself that with the Wicksteed machine he could always push the measurements of extension beyond the accuracy of the machine. In taking a measurement of one ten-thousandth of an inch, he could repeat the measurement as often as he liked and get the same result; but when he came to one millionth of an inch it was no longer so; he could always push the measurement of the extension beyond the accuracy of the measurement of the stress by the machine. The discrepancy might be due to the measuring instrument or to the testing machine. For some time he had regarded it as due to the measuring instrument, and it might be so; but he had certainly come to the conclusion that it was due to inaccuracy of the testing machine, and that he could easily push the measurements of extension very decidedly beyond the accuracy with which the stress could be measured.

Mr. Wicksteed asked what units of stretch and load had been used: whether one millionth of an inch against one millionth of a ton.

Professor Unwin replied that, in repeating four or five times the loading of a specimen, the measurements were accordant only to a certain degree of accuracy, and he could not succeed in getting precisely the same measurement twice. This must mean that he had not put precisely the same stress on the specimen in each repetition; and it could easily be seen how the discrepancy might

(Professor Unwin.)
arise. The Wicksteed machine had a great rough ton weight rolling on rough rollers along a decidedly rough roller path: rough, that is, as a scientific instrument, not as an ordinary piece of engineering work. The accuracy with which stress could be put on the specimen depended on bringing that rough ton weight to exactly the same place on the lever in successive loads. Its position was determined by a vernier, which was something like 2 feet distant from the centre of gravity of the weight itself; and a very slight canting of the weight would make difference enough in the position of its centre of gravity to introduce the amount of error he assumed in the measurement of the stress. Granting that the Wicksteed machine was accurate enough for ordinary purposes, it might be said that nothing better was wanted; but if something better presented itself he did not see why it should not be used, even if it had a limit of accuracy beyond what was ordinarily wanted. The merit of the Emery machine was that, while it had been made as much more delicate and sensitive than an ordinary machine as a chemist's balance was in comparison with a grocer's scales, this result had at the same time been attained by means which rendered the more sensitive machine less liable to injury, less liable to wear, and less liable to get out of order, than the ordinary machine. Admitting that the sensitiveness of the Emery machine was beyond that ordinarily necessary in commercial testing, that sensitiveness might not be an advantage, but at all events it did not seem to him to be a defect.

It had been suggested (page 234) that the Emery machine was not adapted to an autographic apparatus; but Mr. Wicksteed's own autographic apparatus could be applied to it as easily as to his own machine. He had also been told that Mr. Emery had devised an autographic apparatus of a perfectly accurate kind. At all events he was satisfied that there was no difficulty whatever in having a perfect kind of autographic apparatus attached to the Emery machine.

The broad difference between the two machines was that the Wicksteed machine was one of low multiplying power, while the Emery was one of extremely high multiplying power. At one time indeed he had been inclined to think that on the whole a large

multiplying power was not desirable, because he could not be sure that all the leverages had been properly tested; and he had therefore been content with a low multiplying power. But on reconsidering the matter he was now disposed to think that the higher the multiplying power the better. What was wanted in a testing machine was the quickest and most instantaneous indication that the load was either a little too heavy or a little too light; and on looking into the subject he had come to the conclusion that the indication the machine gave, as to whether it had got too much or too little load, was absolutely independent of the multiplying power, if the inertia of the levers of the machine were neglected. After a pretty long experience he had a little reluctantly come to the conclusion that, though the Wicksteed machine was sensitive enough as a statical weighing machine, it was the most sluggish testing machine with which he was acquainted. Its sluggishness mainly arose out of the very large inertia of the four-ton lever which was used to carry the large rolling weight of one ton. The opinion he knew was constantly expressed, that the influence of inertia was more prejudicial in a machine of high than of low multiplying power; but after five or six years' experience he had come to the contrary conclusion.

The President was glad the discussion had been carried so far, because it had at any rate brought out some features of the Emery machine which had perhaps not been apparent at first sight. The Members he was sure would examine the machine with great interest as soon as it was put up in this country, when they would be better able to judge of its merits. As one main feature of the Emery machine seemed to be the employment of the flexible diaphragms in the two hydraulic chambers, he had asked Mr. Sterne kindly to lend the two specimens now exhibited of the Springer torsion balance. Instead of depending upon knife-edges, this machine was balanced on flexible strips of thin steel ribbon, which underwent a very slight twisting backwards and forwards as the balance moved up and down. For anyone interested in weighing machines he believed it would be worth while to look into this as a favourable contrivance for a sensitive and accurate balance.

(The President.)

As it appeared to be the general wish of the meeting that the discussion upon the Emery machine should not be closed, but should be resumed after there had been the promised opportunity of seeing the machine in this country, he would now adjourn it accordingly to be re-opened at a future meeting.

Mr. TOWNE wrote that so much ground had been covered in the discussion, and so many questions had been raised touching the mechanical principles involved in the Emery testing machine, as to call for a somewhat extended reply, wherein the several points would be considered in the order in which they had been raised by the successive speakers; and in the preparation of this reply he had been assisted by Mr. Emery.

In page 226 Mr. Walker speaks of "undue friction arising from the pistons." In the weighing apparatus of the Emery testing machine there are no pistons whatever, in the ordinary sense of that word. As shown in Fig. 11, Plate 36, the movable part D of the hydraulic chamber is seated on the sealing diaphragm, and does not even touch the surrounding ring or casing N, but is connected to the latter solely by a flexible fixing diaphragm V of large free span, usually about 0·65 inch, and of 0·012 inch thickness. The action of these parts involves no friction whatever, friction implying lost work.

With Mr. Adamson's reference (page 227) to the variations and inaccuracies of ordinary pressure-gauges the author entirely agrees. An extensive experience in their use has developed an ordinary rate of error ranging from 3 to 20 per cent. It is pertinent to remark that the makers of the Emery testing machines have also constructed pressure-gauges of large capacity and of extreme fineness upon the same principles of design as are embodied in the testing machine, and that in these gauges the rate of error is guaranteed to be within one-half of one per cent. for ordinary work, and within one-tenth

of one per cent. for gauges of the higher class. This degree of precision, although unusual, is much less than that of the Emery testing machine itself, which is in fact a gauge for recording pressures, and as such possesses remarkable delicacy and durability. In the finer of the pressure-gauges above referred to, which indicate up to 2000 lbs. per square inch, the dial has a diameter of 20 inches, and the needle-point travels 60 inches in indicating the load of 2000 lbs., or at an average rate of one inch for each $33\frac{1}{3}$ lbs. per square inch. But in the 300,000 lb. testing machine the needle travels at the rate of 91 inches for the same $33\frac{1}{3}$ lbs. change of pressure. In the fine pressure-gauges the main resisting spring is a flat steel plate, fixed at one end, and bent through only a slight angle even when in the extreme position due to the maximum load. It is gold-plated to protect it from atmospheric action, is contained within a dust-tight case, and is of such construction and so employed as to be entirely unchanged by long years of use. The hydraulic chamber of the testing machine has three elements of resistance:—firstly, the resistance due to bending the flat sheet-metal diaphragm, which in the reducing chamber contained in the weigh case is about 3·8 inches diameter, 0·007 inch thick, and with 0·06 inch free span, moving either up or down as the indicator bar moves from its zero point, the maximum oscillation of the needle being 0·8 inch from the zero point, and the movement of the diaphragm being therefore limited to 1–25,000th of an inch either way; secondly, the resistance of the fulcrum-plates; and thirdly, the dead weights added to the poise-rods of the second lever, these weights being of bronze, gold-plated, untouched by the hand, situated behind plate-glass with dust-tight joints, and in the fullest sense permanent and unchangeable. The first and second of these resistances arise entirely from molecular changes in the several parts, and not from the friction of one part on another; they therefore give rise to no lost work. It is important to note the distinction herein made between friction, which implies lost work, and elastic resistance, which implies energy stored up and given back. The rate of motion of the needle or indicator is adjusted by means of the sensitising weight E, Fig. 17, Plate 38. By raising this weight on

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the rod which carries it, the scale is made more sensitive: that is, the indicator bar will move further on the application of a given load upon the platen of the machine than it would if the weight E were lower on its supporting rod. The sensitising weight is adjusted by trial in such a position that a load of 100 lbs. placed on the platen of the machine will move the point of the indicator just 0·8 inch. This space is then graduated into ten equal parts, each representing a change of 10 lbs. Hence when the scale is balanced and the indicator bar stands at zero, a load of 10 lbs. placed on the platen will cause the point of the indicator to move to the first or 10 lb. graduation; and so on up to the limit of its vibration. This enables the reading of small loads to be taken directly from the vibration of the indicator bar, if desired.

In page 228 Mr. Adamson objects to specimens having a larger sectional area than half a square inch. Tests of large specimens have demonstrated repeatedly the danger of inferring their total strength from that of a small specimen cut from the larger one, unless it is known certainly that the whole is free from initial strains due to unequal cooling, hammering, rolling, or other like causes. The objection that in testing larger bars the specimen is apt to break on the outside sooner than the inside is one depending largely upon the kind and form of material tested. Round or square bars of ductile metal, having a length of ten diameters exposed between the holders or grips, may always be expected to break without pulling the outside faster than the middle, the whole of the section being extended about equally until the extension of the bar as a whole has nearly ceased, and breaking begins to be indicated by a weakness shown at the point where rupture finally takes place. The same is practically true of flats, if their exposed length is equal to ten times the width of the plate; and their exposed length should not be less than this, unless indeed it is carried to the opposite extreme by being made very short, say not exceeding one-tenth of the width: that is, plate specimens, in order to avoid tearing, should have a length for their exposed part of not less than ten times their width; or, if this cannot be done, then a length of not more than one-tenth of their width. The latter

specimens will of course carry a much higher load and give much less extension.

In page 229 Mr. Stanger makes the surprising statement that in knife-edges the alterations due to the weight upon them are practically *nil.* On the contrary the author maintains that the deflection of most knife-edges in machines carrying heavy loads is absolutely unavoidable and is seriously objectionable. In many cases they have to carry loads of from 50,000 to 500,000 lbs. per square inch upon their edges, and it certainly cannot be asserted that such loadings will not cause sensible compression; they are rather of such a character as actually to destroy the fine edges, and cause the latter to imbed themselves into the bearing plates, so that under these heavy loads the knife-edge frequently rests in a sensible bed or seat. As it expands under the reduction of its load, the elasticity of the metal may permit it to roll again on its normal seat, instead of rotating and sliding in it; but under the weights above supposed the yielding and deflection are certainly sensible, and undoubtedly give rise to frictional resistance, that is, loss of power. The statement that the pressure exerted by one finger is sufficient in a certain machine to produce certain results seems rather out of place in connection with instruments of precision. Such results depend entirely upon the leverage or multiplication of power in the particular machine, and are not at all reliable as indicating the freedom of the machine from frictional resistances.

In page 230 Professor Barr expresses doubt as to the correctness of the statements made in regard to "the weighing of the stress upon the specimen" in the Emery machine, and thinks that there is a difference between the weighing of such stresses and of a dead weight. It is immaterial however to the scale whether a certain stress, say 250,000 lbs., be put upon it by gravity acting upon some mass to give this pressure upon the platen of the scale—that is to say, by a mass of this weight,—or whether the stress is simply due to a strain of the same amount or intensity brought upon the platen of the machine by a specimen. If the strain on the specimen were 250,000 lbs. as supposed, weights would be put upon the weighbeam of the scale to balance it up to say 249,950 lbs.; but the strain or pressure in this

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supposed case being 50 lbs. more, the scale would be unbalanced by that amount, and the indicator would move to the 50-lb. notch on its scale, or 0·4 inch from zero. This would give a movement of the platform of 1–600,000th of 0·4 inch, or 1–1,500,000th of an inch; and the diaphragm of the smaller chamber or reducer in the scale case would move 30 times this distance, or 1–50,000th of an inch. To move the diaphragm this latter distance, about 1–4,900th of a cubic inch of liquid must pass into the reducer; and to force this liquid through the small pipe 50 lbs. would be acting at the outset; but when the indicator reached its place of equipoise at 0·4 inch from zero this force or weight would be balanced by the elastic scale resistances, and there would be just no pressure left, and motion would cease. In other words, the elastic resistances of the machine, including the bending of the stay plates, fulcrums, and diaphragms, would in all just balance this 50 lbs., and the indicator would stand at 0·4 inch from zero, that is at the graduation denoting 50 lbs. If clear alcohol were used in the chambers and pipe, the indicator would start too quickly, and by its inertia would pass the place of balance or equipoise; but by mingling a little glycerine with the alcohol its fluidity is diminished, and the rate of motion thereby retarded, so that ordinarily the indicator point does not move much, if at all, beyond the place it should reach. If too little glycerine be used, the motion of the indicator is apt to be too quick, and the indicator will go too far, and then has to be returned to the balancing point; while if too much glycerine be used, the indicator will be sluggish and will not reach its balance quickly. The proper proportions have been well determined by experience.

In page 230 Professor Barr criticises the statements made as to the wide range of speed which the Emery machine admits of. It may be conceded that no one would use the higher speed of one foot per minute in actual testing; but it is often desirable and very convenient to use this speed in the interval of removing and replacing specimens. Neither would anyone think of testing specimens at a uniform rate of one-thousandth of an inch in half an hour. Yet both of these extreme rates of motion are often used in testing a single specimen for elastic limit, stretch, and ultimate load. The perfect control of motion

obtainable in this machine enables these changes to be effected and such work to be done very quickly. An Emery testing machine of 70,000 lbs. capacity has repeatedly tested twenty specimens of hard-drawn copper-wire per hour, the observations including stretch and ultimate load in each specimen; the wire was only one-tenth of an inch in diameter, the length exposed between the holders was 40 inches, and the stretch ranged from 1 to 3 per cent. and more. These results would not be possible except in a machine having facility for wide and rapid variation in speed of motion.

In page 231 Professor Barr considers the effect of neglecting for one second the adjustment of the poise-weights in the Emery testing machine, and states that in that time the indicator would attain a velocity of 600 inches per second; whereas, as a matter of fact, even if the specimen were so large as to be unyielding, or insensibly elastic, no such event would happen. What would occur is this: the motion of the lever carrying the poise-rods is limited by the stop-screws to the distance attained when the indicator has moved 0·8 inch; if the indicator should move this distance in one second, the inertia would be exceedingly small, since 0·8 inch per second is only 1–750th part of the velocity he estimates, and the moving force would therefore be only 1–562,500th part of what he assumes. This blow from so small a mass would be so slight as to do no harm to a fly, if its whole force should happen to fall on it; as will be better understood when it is considered that the load required on the point of the indicator for causing it to vibrate through its whole motion of 0·8 inch is only $1\frac{1}{6}$ grain. The motion of these parts cannot be instantaneous, as they are elastic. As a matter of fact, no injury occurs to the indicator from the instantaneous release of the strain of 300,000 lbs. in breaking a steel specimen; as concerns the indicator, if the scale is balanced it is immaterial whether the load of 300,000 lbs. is suddenly removed or instantaneously applied. The former event may frequently occur in the machines as used; the latter can never occur. But supposing that the speed could not be controlled, and was limited to one inch in 500 seconds, and that the specimen was of tool steel, 2 inches square and 2 inches long; then in any one second, if there were no yielding of the machine, the load would compress this block of steel

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one-thousandth part of its length, and would be equivalent to about 30,000 lbs. per square inch, or a total of 120,000 lbs., and in less than three seconds the whole load allowed would be placed on the machine. Can it be supposed that either the Emery machine or the Wicksteed machine could weigh such a strain in any such time? Possibly all the balance-weights in the Emery machine might be thrown on in the three seconds; but surely the one-ton poise-weight in the Wicksteed machine could not possibly be moved out from the rear to the balancing point and there brought to rest in that time; it might be rapidly pushed out in the proper direction, but could not possibly be stopped and brought to the balancing point in so short a time.

A fine and reasonably unyielding testing machine should permit of any desired piston-speed between one foot per minute and a rate as small as zero, the machine in the latter case standing absolutely still while careful tests of length are being made. But this statement does not imply that either of these extremes of speed shall be adhered to throughout the test. Imagine a steel specimen of 3 square inches section, 60 inches long, and having a limit of elasticity of 60,000 lbs. per square inch, and an ultimate strength of 100,000 lbs. per square inch with an elongation of 20 per cent. With a uniform rate of motion of 0·001 inch per second the total stretch of 12 inches would require $3\frac{1}{3}$ hours; but assuming the machine to be unyielding, and the elastic stretch to be 0·000035 inch for each 1,000 lbs. and for each inch of length, the limit of elasticity of the specimen would be reached in 126 seconds, a time quite short enough to weigh the loads carefully all the way up to this point, after which the speed up to the point of breaking may be many times increased. If this same specimen were only 6 inches long, instead of 60, the same suppositions would give the time for reaching the elastic limit at only 12 or 13 seconds; but the yielding of the machine would sensibly prolong this time. What is practically done is at once to run the strain up in a few seconds to about 100,000 lbs., and then to run it gradually in a few more seconds to nearly the limit of elasticity, proceeding very slowly to the actual limit, and carefully keeping the scale balanced within the

limits of the indicator movement until the elastic limit is passed: after which the press is moved much more rapidly to the point of rupture, and the test is completed. A machine of the kind described in the paper has easily tested twelve to fourteen specimens per hour for elongation, elastic limit, and ultimate strength.

In regard to the motion of the fluid in the small tube (page 231), it should be remembered that, instead of the liquid in the larger or main hydraulic chamber moving out of it through the connecting tube to the smaller chamber or reducer at a rate due to the motion of the plunger of 0·001 inch per second, which would require the displacement of about 0·343 cubic inch of liquid, a displacement of 1–4,400th of a cubic inch, or less than 1–1,500th of the above, would move the weight lever against one of its stops, whereupon further flow of liquid would cease, and the tube friction would become zero at the time the motion ceased. This latter fact is true also as to the conditions obtaining when the indicator is in equipoise at any point between its stops: friction of the fluid then disappears, and becomes *nil.*

In page 233 the opinion is expressed that there is no case against the use of the knife-edge for a testing machine. Yet a 75-ton knife-edge testing machine of one of the best known forms has repeatedly thrown its main levers and knife-edges entirely out of their seats at the time of rupture of a specimen. This action is certainly damaging, and is to some extent inseparable from the knife-edge construction. The test of the Wicksteed machine (page 233) involved a specimen of ductile iron 9 feet in length. If the specimen had been only 2 inches or 1–54th part as long, the motion of the lever due to the stretch of the specimen would have been proportionately reduced, and would have been only 1–54th part as much: a motion quite too small to be seen with the ordinary short specimen. In the test referred to, the motion of the one-ton balance-weight was 43 times the motion due to the stretch of the specimen; while in the Emery testing machine the motion at the point of the indicator would be 600,000 times as great as that of the specimen. In the latter case the least change in the stress on the specimen, whatever its length, would be directly visible. For example, if the specimen

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were but one inch long, a change of one-millionth of its length would move the indicator point 0·4 inch, which is practically 40 times the movement necessary to be distinctly visible.

The objection that the application of a number of separate weights would result in an intermittent increase of load (page 234) does not apply to the Emery machine, for the reason that the arrangement of supply valves and weight levers enables the adjustment of the balance weights to the variations of the load to be made with ease, quickness, and precision. In practice the valves are easily adjusted so as to give a continuous increase of pressure, and with equal ease this regular increase of pressure is met by the successive addition of poise weights, usually of the smaller size. These two functions are easily accomplished by a good operator with such nicety as to keep the point of the indicator bar floating close to the zero point, and rarely vibrating more than a few hundredths of an inch either way.

In the author's opinion it is an error to contrast the action of a dead-weight machine with that of the Emery machine. The Wicksteed machine referred to by Professor Barr, requiring a weight of one ton to balance a strain of fifty tons, multiplies only fifty times, and in some respects approaches closely to what may be called a dead-weight machine, when compared with the Emery machine which multiplies 15,000 times between the load and the weight, or 300 times the multiplication of the other machine. Let us now consider the resistance at the specimen tending to move the weights in the two machines with the load of 43 tons mentioned by Professor Barr (page 234), supposing the specimen to change at the rate he mentions of 0·001 inch per second. The motion of the balancing weight weighing one ton will be 0·043 inch per second, if the motion of the lever is proportionate to the strain; to which must be added the resistance of the four-ton lever itself. If we assume the lever resistance due to inertia to be equal to one-third of its weight, acting at the point where the movable weight is placed—an arbitrary assumption,—then the inertia resistance of the lever will be as follows. The vibrating or moving load will be 2⅓ tons, moving with a velocity of 0·043 inch per second; and the work at the specimen to give this movement

will be $\frac{1}{2}mv^2 = \frac{1}{2} \times 2\frac{1}{3} \times \frac{2240}{32 \cdot 2} \times \left(\frac{0 \cdot 043}{12}\right)^2$. In the Emery machine the weights required to balance 43 tons are less than 6 lbs.; adding 8 lbs. as the equivalent of the weight of that part of the lever to be moved, we have 14 lbs. requiring to be moved 0·02 inch per second, this distance being the whole extent of motion that is permitted; the corresponding work will therefore be $\frac{1}{2}mv^2 = \frac{1}{2} \times \frac{14}{32 \cdot 2} \times \left(\frac{0 \cdot 02}{12}\right)^2$. These two amounts are to each other as 1726 to 1; but the leverages of the weights in the two machines are to each other in the inverse ratio of 15,000 to 43, or about 350 times greater in the Emery machine. In the Wicksteed machine therefore the specimen in order to move its weight and lever must do more work than in the Emery machine in the proportion of 1726 to 350 or nearly five times.

It has already been pointed out that the movement of the weight lever from its position of even balance to the extreme limit of its motion either way can cause an extension or compression of the specimen of only 1–750,000th of an inch in the Emery machine; but in all lever machines this change of length due to the motion of the weight levers is very much greater, and often inadmissibly so. Thus if the weight is multiplied 200 times, and the weight lever is allowed 0·4 inch of motion, which is a common proportion, the vibration of the lever makes a change in the length of the specimen of $0 \cdot 4 \div 200 =$ 1–500th of an inch, an amount that is entirely inadmissible in short specimens and causes very severe strains.

The further statement is made (page 233) that on reaching the climax of strain the indicator of the Emery machine would become stationary. This again is not so in fact; the indicator will not become stationary, because it is no longer balanced, since the strain runs up or down according to the variations in the stretch, depending on the rate at which the load is applied; but in the case of all ductile specimens the load will be much reduced before breaking occurs. Any change in the load immediately disturbs the balance of the indicator. In any case the weights can be moved to balance the strain much more easily in a multiple-lever machine than in one having only a single lever, because the weights in the former are

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much smaller and have to be moved through so much less distance. In the Emery machine the weights are smaller, and, although multiplying vastly more than in any single-lever machine, have to be moved but a slight distance in order to be placed on the lever or taken off it. In the case of an absolutely dead-weight machine, having no leverage whatever, it is hardly possible with a specimen of high elastic resistance to know just what fraction of the last added weight is sufficient to break the specimen. Thus if the specimen is loaded to 60,000 lbs., and is expected to carry 80,000 lbs. before breaking, and weights are being added of 5,000 lbs. at a time, smaller weights would naturally not be used until the supposed breaking strain was nearly reached. But it may happen that the first 5,000 lbs. added to the 60,000 lbs. breaks the specimen, in which case it would not be known what was the true strain at which the specimen broke, but only that it supported 60,000 lbs. and broke under 65,000 lbs.

In page 235 Professor Barr criticises the comparison in the paper with a testing machine in which the load is measured by intensity of hydraulic pressure, and refers to the latter as one "which every engineer allowed was exceedingly bad." The author's justification for such a comparison is the fact that the largest testing machine yet built in the United States is of this kind, having a capacity of 1,200,000 lbs., and that it has been highly praised by several engineers. Such a machine may justly be severely criticised, but it certainly cannot be ignored.

In page 236 Mr. Schönheyder expresses the opinion that the motion of the piston in the Emery machine must be greater than only one-thousandth of an inch; and argues that under heavy pressures the piston must be liable to move further, and to make contact with the underside of the hydraulic chamber. But how can it be possible for the piston, having its maximum motion limited to 0·001 inch, to touch the bottom of a chamber having a depth of 0·015 inch? Surely the pressure of 600 lbs. per square inch on the fluid may be relied upon to hold the thin sealing diaphragm up against the under surface of the piston and in close contact therewith. If the chamber is 0·015 inch deep, and there is any considerable pressure on the

liquid therein, as is always the case even when there is no load on the platen of the machine, this initial pressure, and any increase thereof, will tend always to keep the thin brass lining diaphragms close against the top and bottom surfaces of the chamber, leaving between them a thin film of liquid having a depth of about 0·015 inch. Figures already given show that the motion of the piston is limited to less than 0·001 inch by the relation of the several moving parts of the machine, the greatest free motion of any part being at the point of the indicator bar, where it is 1·6 inch. In reality the motion of the piston is much less than 0·001 inch, though how much less cannot be accurately ascertained. The tube connecting the main hydraulic chamber with the reducer holds less than one cubic inch of liquid, and with the full load on the machine this tube would expand much less than 1–10,000th part in area. When the maximum load is put on, the motion of the piston in the smaller chamber or reducer, due firstly to the motion of the indicator and secondly to the yielding of the intervening parts, has been ascertained by actual measurement to amount to less than 0·0006 inch, which involves a supply of liquid from the larger chamber and gives a motion from these causes to the larger piston of less than 0·000025 inch, or about 1–40th of the whole amount of motion allowed. But the yielding of the diaphragm in the larger chamber may add sensibly to this; and the compression of the liquid and of its small amount of contained air will give sensible motion. Supposing the liquid to contain 1 per cent. of air, which is a safe assumption, the entire compression of the air would permit the piston to move 1 per cent. of 0·018 inch, that is 0·00018 inch: the depth of the chamber being here taken as 0·018 inch instead of 0·015 inch, in order to allow for the liquid contained in the tube and smaller chamber. Thus the actual motion of the piston from all causes is probably not more than one-fifth of the 0·001 inch allowed, as it must be remembered that when no load is on the specimen the scale is balanced with an initial load of from 6,000 to 8,000 lbs. on the larger hydraulic support, due to the weight of the load-beams and yoke, and the tension of the initial load-springs.

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In page 237 Mr. Wicksteed enquires whether the rating of the Emery machine has been done at different temperatures. The work of rating these machines has always been done at the ordinary temperatures existing in the workshop, the range of variations extending to perhaps 40° Fahr. The experience thus far gained does not indicate that these changes of temperature sensibly affect the rate of weighing; they do however disturb sensibly the balance of the scale. The total volume of liquid, if referred to the area of the larger hydraulic support, is equal to a depth of about 0·018 inch; and its volume changes more rapidly than that of its containing walls. It would rarely vary however, between two successive balancings on the same day of use, more than 1–2,000th of its volume. The expansion of the air is vastly greater than that of the liquid; but the quantity of air is very small, as great pains are always taken to expel it. If however, as above, it be supposed that the liquid contains 1 per cent. of air, and that the air changes 1–18th in volume under the maximum change in temperature, this change would give a movement of $\frac{1}{18} \times \frac{1}{100} \times 0 \cdot 018 = 0 \cdot 00001$ inch. If at the same time the liquid also changes its volume 1–600th part by the change of temperature, this change would give a movement of $\frac{1}{600} \times 0 \cdot 018 = 0 \cdot 00003$ inch. The total change of volume due to expansion or contraction of both the liquid and its contained air would thus cause a movement of the piston in the hydraulic support of 0·00004 inch. All the stay plates, fixing and pressure diaphragms, must be moved an equal amount, and the load required for this will be the amount which the scale is out of balance from these causes. These, while not affecting the *rate* of the scale, constitute a disturbing element in the balance, the exact amount of which is not known; it is so small however that by balancing the scale between every test, as should always be done with a fine scale of any construction, even this minute source of error is eliminated. The arrangement of the scale in the Emery testing machine provides for this balancing, whenever required, in the most convenient manner. No attempt has been made to ascertain the exact amount of this minute but sensible disturbance, which is only sensible for the reason that

the scale in the Emery testing machine is so delicate as to show distinctly a pressure even so small as is required to bend the horizontal stay plates and diaphragms through the above minute distance of 0·00004 inch. Before beginning a test the scale is always balanced, not by the permanent action of the initial load-springs, but by the small sliding weight W on the indicator bar, Fig. 17, Plate 38.

In page 237 Mr. Wicksteed alludes also to the statement that the testing machine had been rated by means of a rating machine; and objects that no independent proof was obtained, if the latter was itself another Emery machine of the same kind. It is true that the latter machine is one of the Emery type; but it is a lever machine, without hydraulic chambers, and having plate fulcrums, which was rated by dead loads. This machine is absolutely frictionless, and the standard weights used in rating it were known to be true within 5 grains on each 500-lb. weight, and within less than 25 grains on each of the 2,000-lb. weights employed. The use of these standard weights was not carried through the whole range of the rating machine, but only through about one quarter thereof. Up to this point the action of the machine was found to be perfect; and its construction is such as to make it reasonably certain that its rate was the same throughout the whole range of its capacity. By means of this rating machine the pressures on the lever system contained in the scale case of each Emery testing machine are repeatedly carried throughout their whole range, in connection with hydraulic supports of accurately known area used in the rating machine. When the mechanism in the scale case indicates satisfactorily throughout its whole range, it is then connected with its own hydraulic support, which is set in its own testing machine ready for use; and then the fine standard weights are applied directly upon the platform of the machine, in order to see that the scale when thus connected balances them as it is expected to do. These loads are then carried up to a few thousand pounds only, inasmuch as the handling of larger weights would be very difficult, and is not necessary, owing to the previous testing of the scale throughout its whole range in the rating machine,

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as already explained. The hydraulic supports of known area, used in the rating machine, form no component part of this testing machine or of any other testing machine. Supposing that such a support having an area of exactly 80 square inches were used with this rating machine—not as a part of the machine, but inserted in it and there subjected to a load of say 40,000 lbs. as measured on the fulcrum-plate levers of the rating machine,—it would then be known that there was a load of 500 lbs. per square inch on the support, which is placed in the rating machine to receive this known pressure and to communicate it to the small reducing chamber in the scale case of the testing machine which is being rated. The action of this load of 500 lbs. per square inch would be carefully observed on the scale of the testing machine which is being rated. Various loads of known amounts are thus placed upon the measuring support which is set in the rating machine; and the effects of these various loads per square inch are then noted on the scale of the testing machine which is being rated. These loads of known amounts, being applied to known areas, show the action of the testing machine up to the highest pressures ever reached in it; and the endeavour is to make the scale show by its weights and indicator always in the same proportion for all loads or pressures put upon the liquid. The pressures in these tests are carried from the lowest, when there is no load on the platen of the testing machine, up to the highest load that will ever be put upon it. The testing-machine scale is thus rated by actual known pressures on the liquid used in its own reducing chamber, throughout the entire range of pressures which are ever to come upon it. If now the hydraulic support placed in the rating machine in a given test were just one-tenth the area of the hydraulic support to be used in the testing machine which is being rated, then a load of 60,000 lbs. in the rating machine would correspond with a load of 600,000 lbs. in the testing machine, as regards the pressure upon the liquid.

Professor Unwin (page 240) having had the advantage of previously examining one of the Emery testing machines in use, his comments thereon, being based on actual observation, do not require

criticism. His allusions to the delicacy and accuracy of the Emery machine, as contrasted with the best attainments of the simple lever machine, show a full appreciation of the mechanical conditions involved; and he is undoubtedly correct in his conclusion (page 243) that in testing machines "the higher the multiplying power the better."

MEMOIRS.

ROBERT HADFIELD was born in 1830, and received his education in Sheffield. In early life, while acting as assistant overseer and collector of rates at Attercliffe, he took a keen interest in steel manufacture, and all the time he could spare was devoted to studying the intricacies of this subject. In 1865 he was engaged in the manufacture of steel and wire, which was carried on successfully for some years, but he then retired. Shortly afterwards however he acquired the models and patterns of the Kelham Works, and started afresh at the Continental Works, Attercliffe, where such success attended his efforts that it soon became necessary to seek larger premises. He therefore commenced the erection of works specially suited for his requirements in Newhall Road, Attercliffe; these works were enlarged from time to time, and are now known as the Hecla Steel Casting Works of the Hadfield Steel Foundry Company, giving employment to from 400 to 500 men, as compared with 20 or 30 when they were first started. In maturing these works and in developing the manufacture and application of steel he found ample scope for his inventive skill and untiring energy, introducing rapid processes of steel-making, which comprised all that he regarded as the best features of the Bessemer and Siemens-Martin and other processes. From steel of his production were made tools with the finest cutting edge, and steel castings of all descriptions and weights. Large supplies of shot and shell were made from cast steel of such extraordinary toughness and power of resistance, that the shells would pass unharmed through steel-faced plates. After being in failing health for some time, he died on 20th March 1888, at his residence, Broomhill, Sheffield, at the age of fifty-seven. He became a Member of this Institution in 1879.

Thomas Elliott Harrison was born at Fulham on 4th April 1808, being the son of Mr. William Harrison, of Thornhill, Sunderland. After being educated at Kepier grammar school, he was sent at a very early age to the firm of Messrs. W. and E. Chapman, Newcastle-on-Tyne, to learn the profession of a civil engineer and surveyor; and by the time he was twenty years of age he was fully equipped for independent professional work. Soon afterwards he became acquainted with Robert Stephenson, who commissioned him to take the levels from Wolverton to Rugby, for the first application to parliament for the construction of the London and Birmingham Railway. His next work, also under the superintendence of Robert Stephenson, was the survey of the Stanhope and Tyne Railway, thirty-two miles in length, and opened on 10th September 1834; to which was added in 1838 a branch from Usworth to Moorsley on the Hartlepool line, the whole railway being eventually absorbed into the North Eastern. In connection with this line the Victoria Bridge over the Wear was erected from his plans and under his superintendence; it is 157 feet high from the foundation, and has a centre arch of 160 feet span. In 1837 he designed a locomotive engine * for the Great Western Railway, which was worked on that line for some time, and in which the speed was increased by wheel gearing placed on a separate carriage from that carrying the boiler. A full account of his subsequent labours in railway surveying and engineering would practically be a record of the rise and development of the North Eastern Railway. His connection with the Stephensons was broken only by their deaths; he was engaged with them in some of their most arduous undertakings, and with Robert Stephenson especially he maintained a warm friendship. In the survey of the Newcastle and Carlisle Railway he was long engaged; and amongst his works executed at various times in the north may be mentioned the Swinton and Knottingley line, the York and Doncaster, the Hull and Selby, the Tweedmouth and Kelso, and the Spennymoor and Bishop Auckland branches with their

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* See "Practical Treatise on Railroads," by Nicholas Wood; third edition, 1838, page 719. See also Proceedings 1875, page 82.

connections. The last great work of the kind in which he was engaged was the Alnwick and Cornhill Railway. Conjointly with Robert Stephenson he was engineer for the construction of the Newcastle and Berwick and the Newcastle and Darlington lines; and they also shared the credit of designing and building the High Level Bridge between Newcastle and Gateshead. With the construction of the great railway arteries of the north came the period of Robert Stephenson's gradual retirement from railway work in this country; and Mr. Harrison was then appointed engineer-in-chief of the amalgamated York Newcastle and Berwick Railway, and subsequently of the North Eastern Railway, which resulted in 1854 from further extensive amalgamations. In this position he had control over the locomotive department as well as over the permanent way; and continued to hold the title and position until his death. Amongst the great works which he designed and carried out are the Jarrow Docks, opened in December 1858, where several improvements in connection with the construction of docks and the shipment of coals were effected, such as working by hydraulic power the ballast cranes and the machinery for opening the dock gates, and arranging suitable inclines for the coal wagons to run to and from the shipping spouts, thus avoiding the use of shunting engines or horses (Proceedings 1858, page 260). He was one of the first to adopt hydraulic power, using it in 1850 for shunting railway wagons at the Trafalgar Goods Station, Newcastle; for working the swing bridge in connection with the North Eastern Railway over the river Ouse near Goole (Proceedings 1869, page 121); for working other swing bridges at Naburn, Hartlepool, and Middlesbrough; and for working cranes. The recently constructed railway bridge over the Wear at Sunderland was also designed by him, as also the new North Eastern Docks at Hartlepool. Of the many railway stations erected in accordance with his plans may be mentioned those at Gateshead and Darlington, which are among the most recent; and the extension of the Newcastle Central Station is now being carried out from his designs. In 1874 he was appointed a member of the Royal Commission on Railway Accidents. In the question of continuous brakes for railway trains he took great

interest, and after a thorough and careful examination he recommended in 1877 the adoption of the Westinghouse automatic brake on the North Eastern Railway, making valuable suggestions for improving its parts and perfecting its working. During the last quarter of a century his services were in constant demand for arbitration or for consultation in important or difficult engineering works of many kinds. He was consulting engineer to the London and South Western Railway, and to several of the Welsh lines; and he represented the North Eastern Railway on the committee of engineers appointed in 1881 to consider the design of a bridge to cross the Firth of Forth, in connection with which his recommendations were adopted in various respects. His death occurred at his residence at Whitburn near Sunderland on 20th March 1888, within a few days of the completion of his eightieth year. He became a Member of this Institution in 1858.

Albert Lewis Newdigate, the youngest son of Francis and Lady Barbara Newdigate, was born at Blackheath on 29th March 1840. He was educated at Eton and at Christchurch, Oxford, being at first intended for holy orders; but evincing a strong liking for engineering, he was articled to Mr. C. P. B. Shelley, by whom he was employed during his pupilage partly in the office and partly on the Shrewsbury and North Wales Railway, then in course of construction. From the autumn of 1868, and during the three subsequent years, he was employed under Mr. H. Lee-Smith, in connection with the bridge and other designs for the Lahore and Peshawur (now the Punjab Northern) Railway. From 1873 to 1879 he acted as representative of Messrs. Henry Lee and Son, Westminster, the contractors for the Granville Dock at Dover, where he remained until 1879 under the same firm, in connection with the deepening works of the harbour. During the next five years he was also occasionally engaged by Messrs. Lee and Son, until in 1884 he was appointed their resident agent to carry out the foreshore revetment wall and concrete groyne at Hastings, under Sir John Coode. He continued there until November 1886, when he was appointed engineer to the Dover

Harbour Board. This post he held until his death on 7th March 1888, at Watersend, Dover, in the forty-eighth year of his age. He became a Member of this Institution in 1866.

Henry Robertson was born in Banff on 16th January 1816, and after having received his preliminary education in the schools of his native town and at King's College, Aberdeen University, commenced his active career as a railway contractor, carrying out successfully and profitably contracts at Port Glasgow, under Mr. Locke. Subsequently he became connected with the North Wales mineral district, which he did so much to develop. Forty-six years ago, when an effort was made to re-start the Brymbo Iron Works then lying idle, he projected a line or tramway from Brymbo to Connah's Quay for connecting the works with the river Dee. He also projected the North Wales Mineral Line, which ran from Wrexham to Chester, with a branch to Brymbo, thereby affording increased facilities for transit; this line was afterwards extended to Ruabon and Shrewsbury, and forms now a portion of the Great Western main line to Birkenhead and Liverpool. He was largely instrumental in carrying out the whole of the extensions of the Great Western Railway in North Wales, and he originated and completed the Shrewsbury and Hereford line, and also the Central Wales Railway from Craven Arms to Llandovery. About 1850 he became engineer of the Shrewsbury and Birmingham line, then worked in conjunction with the Shrewsbury and Chester. He also projected and constructed the branch line to Coalbrookdale, Horsehays, and other places in the same district; as well as the lines from Ruabon to Dolgelly and from Bala to Blaenau Festiniog. The fine viaducts on the Great Western Railway over the valleys at Cefn and Chirk were designed and erected by him, as was also the Kingsland Bridge over the Severn at Shrewsbury, which is one of the largest single-span iron bridges in the country. In connection with the "battle of the gauges," he contributed in no small degree to the adoption of the narrow gauge in preference to the broad at the time he was projecting the Shrewsbury and Birmingham line. In later years his energies were devoted to the further development of communication between

North Wales and the rivers Dee and Mersey. He accordingly projected, and at the time of his death was carrying out, the Dee extension and the Wirral railways, which are intended to be connected with the Wrexham, Mold, and Connah's Quay extension at Hawarden by means of the Dee Bridge. As proprietor of the Brymbo Iron Works and estate, he transformed the works four years ago into steel works, which are the largest in North Wales; on the estate are the Gatewen and Plaspower collieries, in which work has been carried on with singular regularity. He was the owner of the Minera Lime Works; and early owned the Ruabon Old Brandy Colliery, which afterwards belonged to the Ruabon Coal and Coke Company. Up to the time of his death he was a partner in the locomotive works of Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester, and also in the civil engineering firm of Messrs. Robertson and Mackintosh, London. He was chairman of the Llangollen and Corwen, the Corwen and Bala, the Vale of Llangollen, and the Wirral Railways, the Minera Lime Company, the Broughton and Plaspower Coal Company, the Brymbo Steel Works, and the Brymbo Water Works. He represented Shrewsbury in Parliament from 1862 to 1865, and from 1874, and again in 1880; in 1885 he was returned for Merionethshire. He was a justice of the peace for the counties of Merioneth and Denbigh, besides being a deputy-lieutenant of Merionethshire. His death took place at his residence, Palé, Llandderfel, near Bala, on 22nd March 1888, at the age of seventy-two. He became a Member of this Institution in 1848.

Benjamin Frederick Wright was born in London on 21st March 1845, and after being educated at the Grammar School, Great Crosby, near Liverpool, entered in 1860 the locomotive department of the Great Western Railway at Birmingham, under his brother, Mr. T. H. Wright. In 1862 he went into the drawing office of the London Chatham and Dover Railway at Battersea under Mr. William Martley, being afterwards stationed at Chatham and later at Dover in charge of the out-door locomotive departments. He next went to the South Eastern Railway at Tunbridge under Mr. A. M. Watkin.

In March 1878 he left England for Japan, to take the superintendence of the locomotive, carriage, and wagon department of the Tokio section of the Imperial Railways of Japan, in which position he had a very successful career for upwards of ten years. His death took place at Kobe, Japan, on 13th February 1888, in the forty-third year of his age. He became a Member of this Institution in 1881.

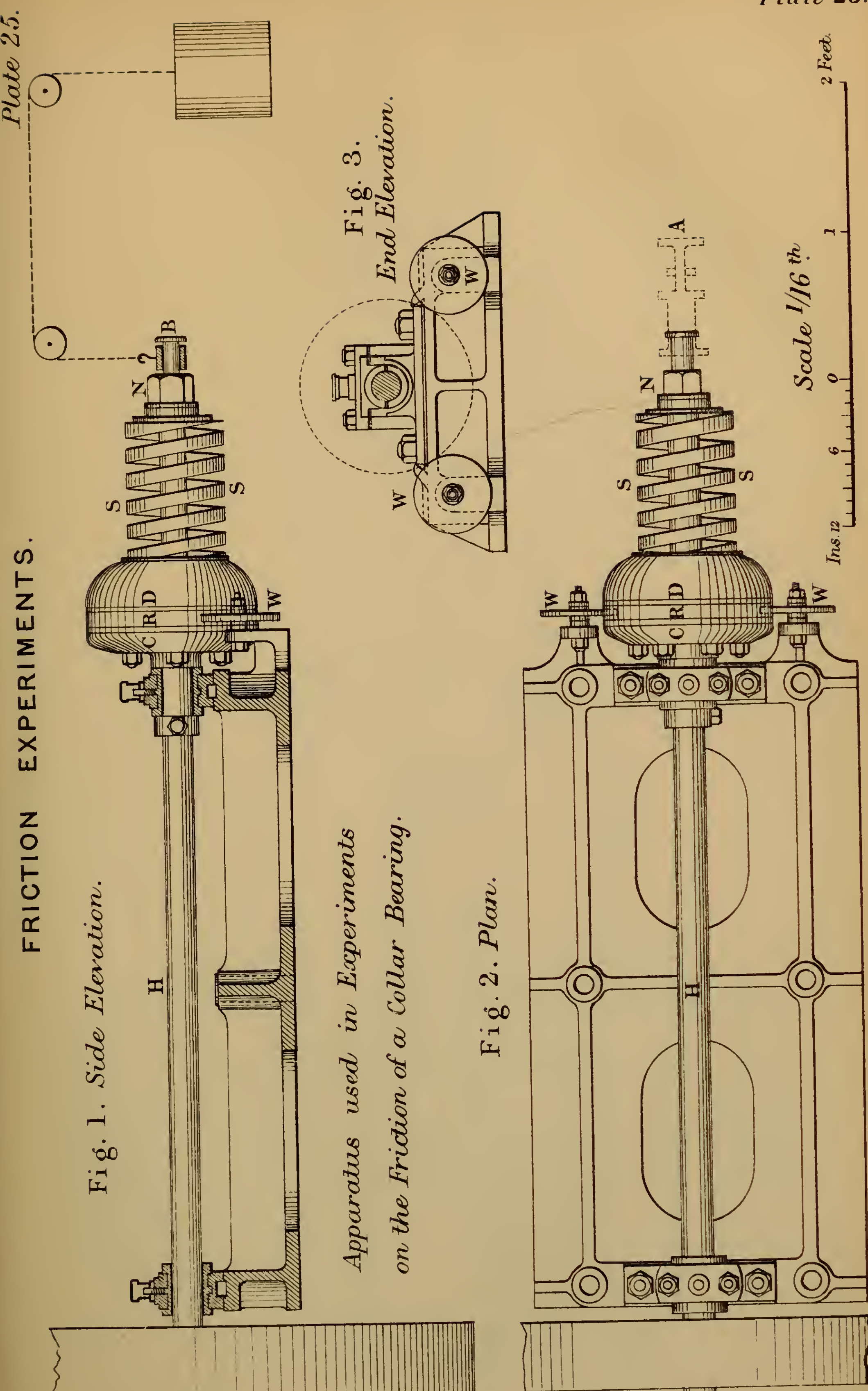
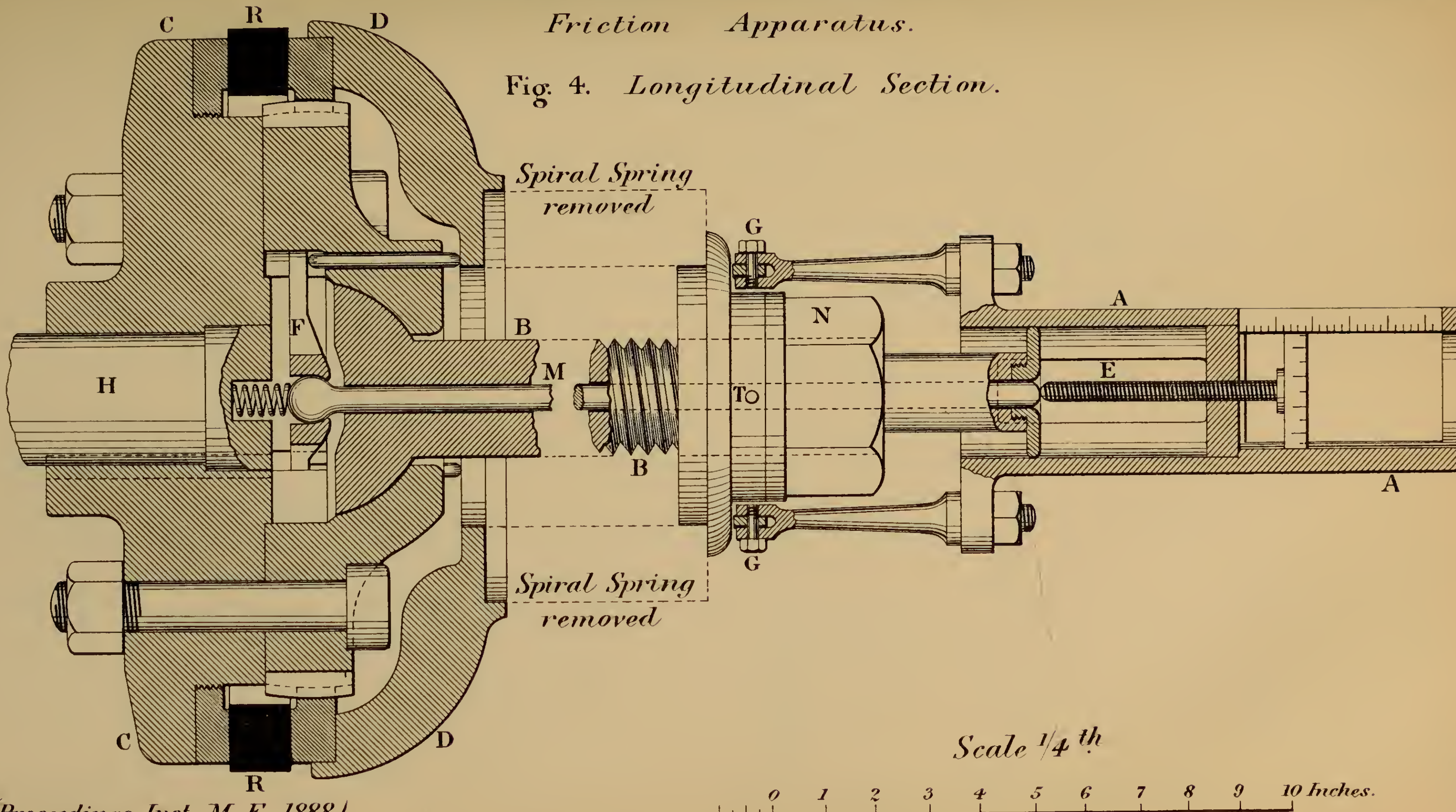


Plate 25.
FRICTION EXPERIMENTS.
Fig. 1. Side Elevation.
Fig. 2. Plan.
Fig. 3. End Elevation.
Apparatus used in Experiments
on the Friction of a Collar Bearing.
Scale 1/16 th
Ins. 12
6
0
1
2 Feet.
A
B
N
S
C
R
D
W
H

FRICTION EXPERIMENTS.

Friction Apparatus.

Fig. 4. *Longitudinal Section.*



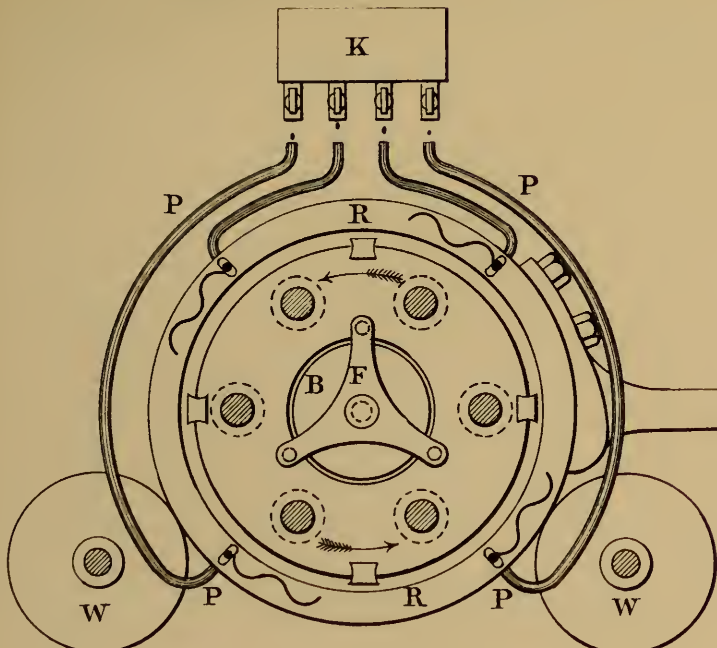
(Proceedings Inst. M. E. 1888.)

Plate 26.

FRICTION EXPERIMENTS.

Friction Apparatus.

Fig. 5. *Transverse Section.*



Scale 1/8th.

0 5 10 Inches.

Measuring Apparatus.

Fig. 6. *Elevation.*

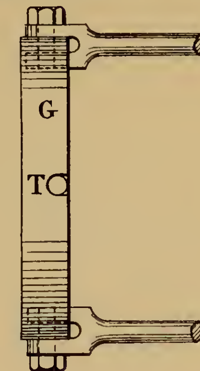


Fig. 7. *Transverse Section at XX.*

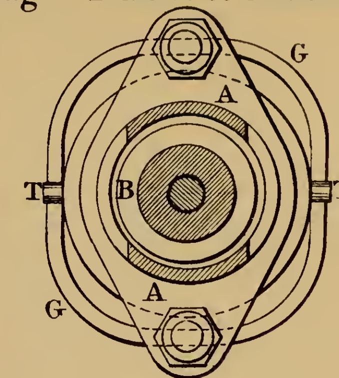


Fig. 8. *Transverse Section at YY.*

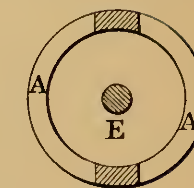
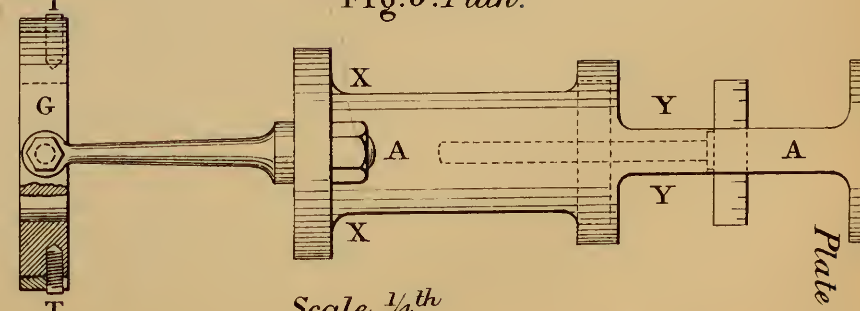


Fig. 9. *Plan.*



Scale 1/4th.

0 1 2 3 4 5 6 7 8 9 10 Inches.

(*Proceedings Inst. M.E. 1888.*)

Collar Bearing.

Fig. 10.

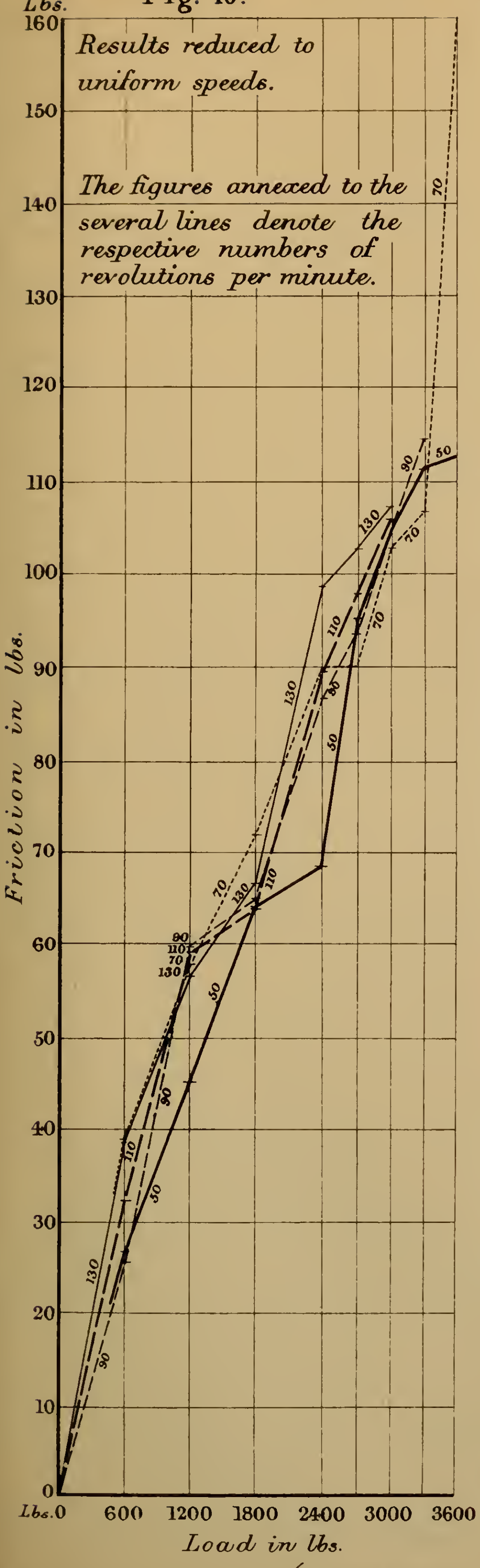
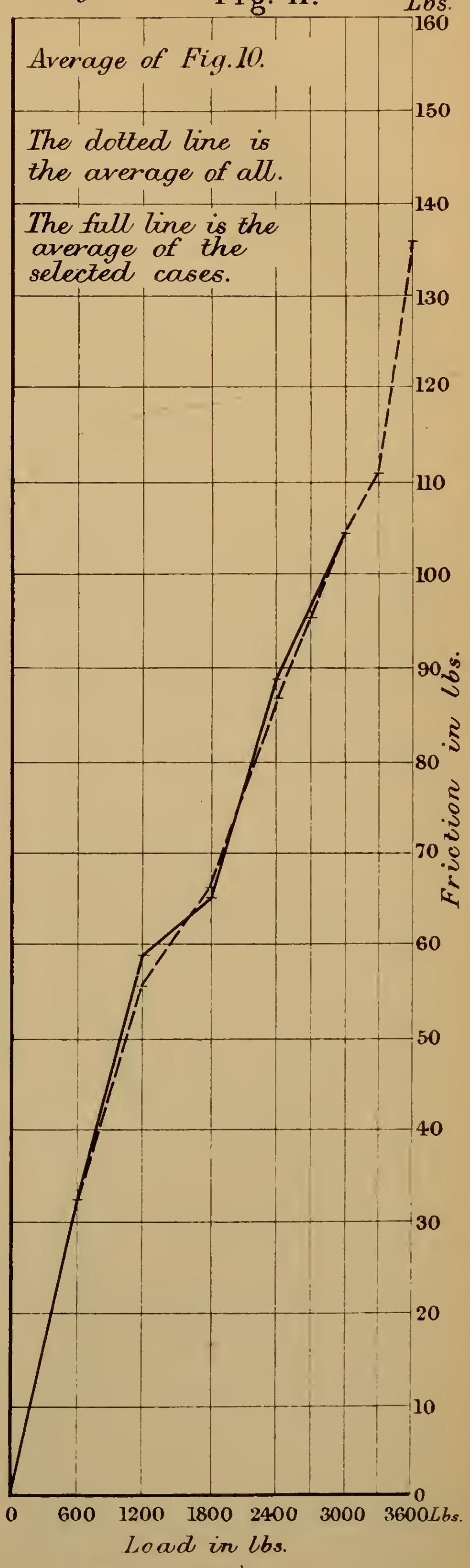


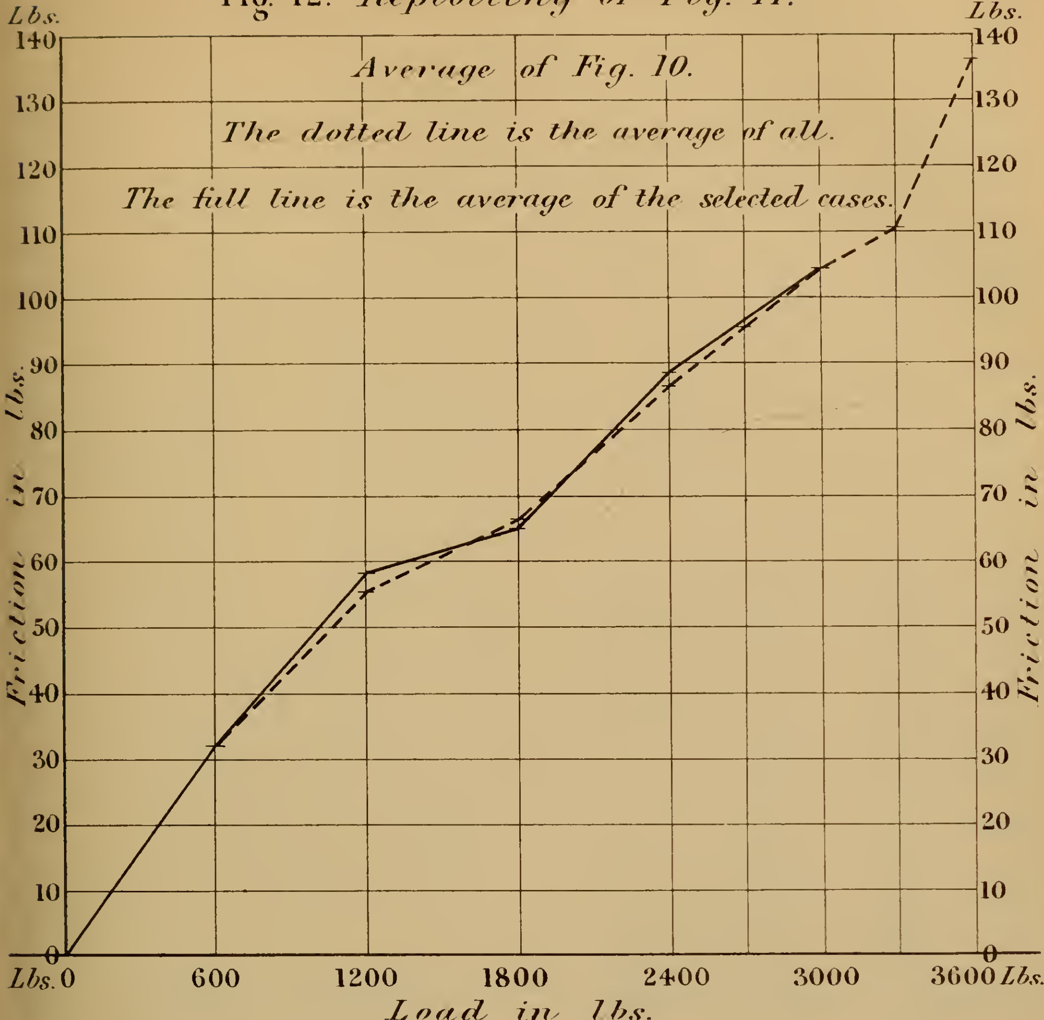
Fig. 11.



(Proceedings Inst. M. E. 1888.)

Thrust Bearing.

Fig: 12. *Replotting of Fig. 11.*



Lubrication of Bearings.

Fig: 13. *Journal.*

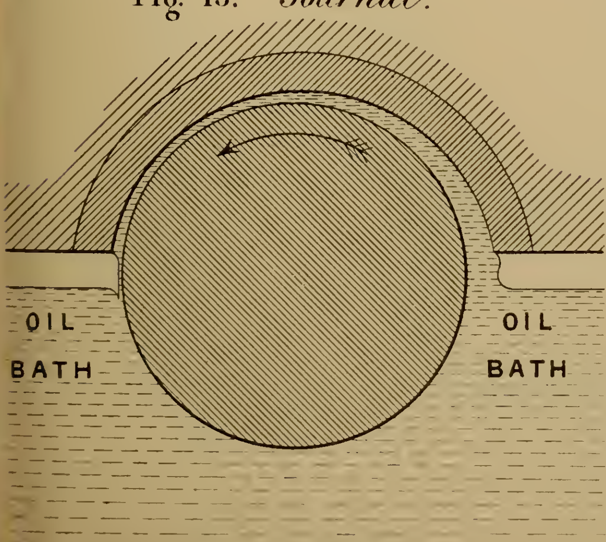
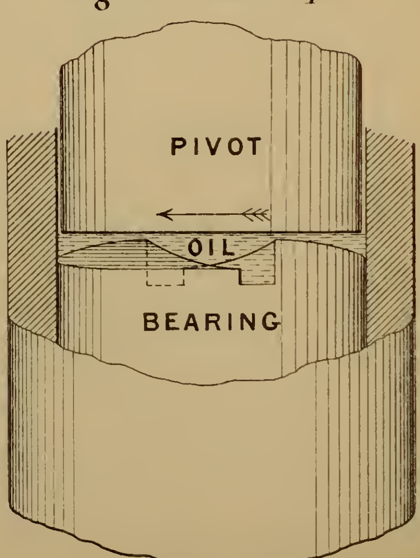
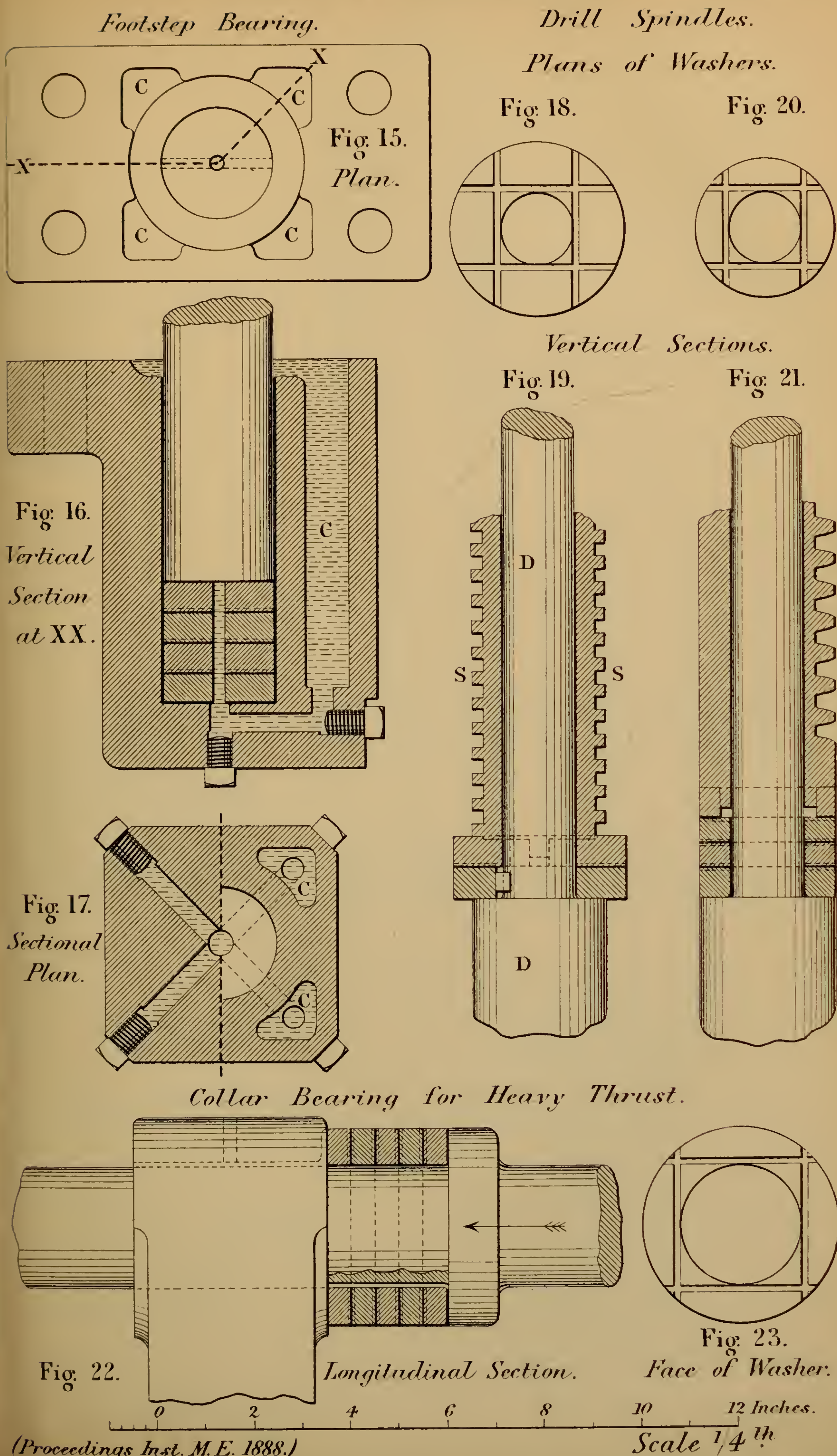


Fig: 14. *Footstep.*



(Proceedings Inst. M. E. 1888.)


Footstep Bearing.
Drill Spindles.
Plans of Washers.
Fig: 18.
Fig: 20.
X
C
C
C
C
X
Fig: 15.
Plan.
Vertical Sections.
Fig: 19.
Fig: 21.
Fig: 16.
Vertical
Section
at XX.
C
D
S
S
D
Fig: 17.
Sectional
Plan.
C
C
Collar Bearing for Heavy Thrust.
Fig: 23.
Face of Washer.
Fig: 22.
Longitudinal Section.
0
2
4
6
8
10
12 Inches.
Scale 1/4 th

Drill Spindle.

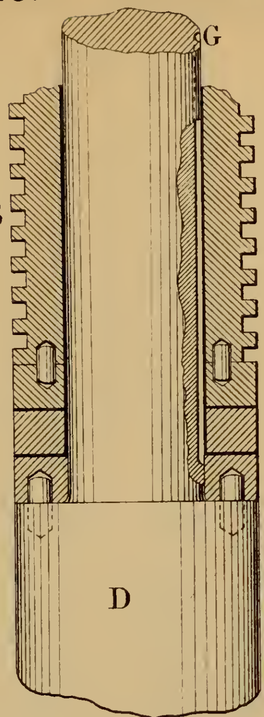


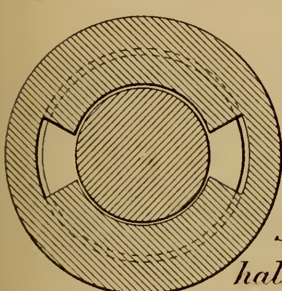
Fig: 24.

Vertical Section.

Scale half size.

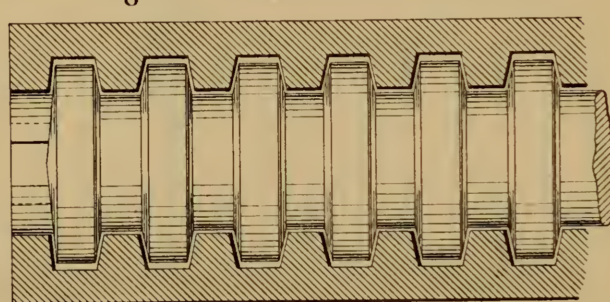
Thrust Collars with inclined faces.

Fig: 25. *Transverse Section.*



Scale half size.

Fig: 26. *Longitudinal Section.*



Collar Bearing.

Fig: 27.

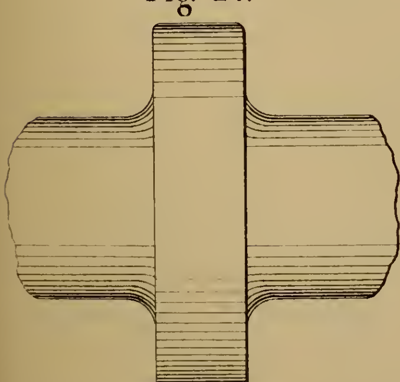
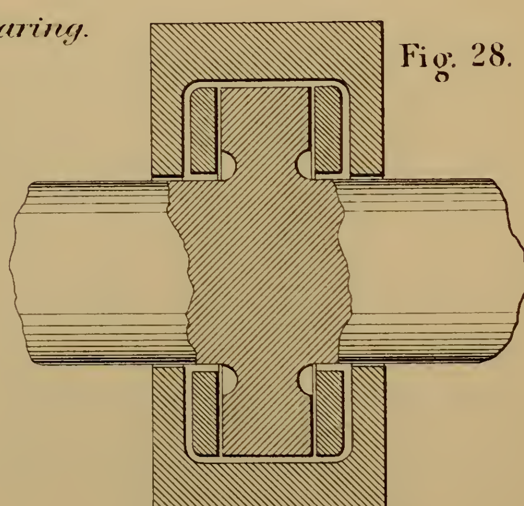


Fig: 28.



Scale half size.

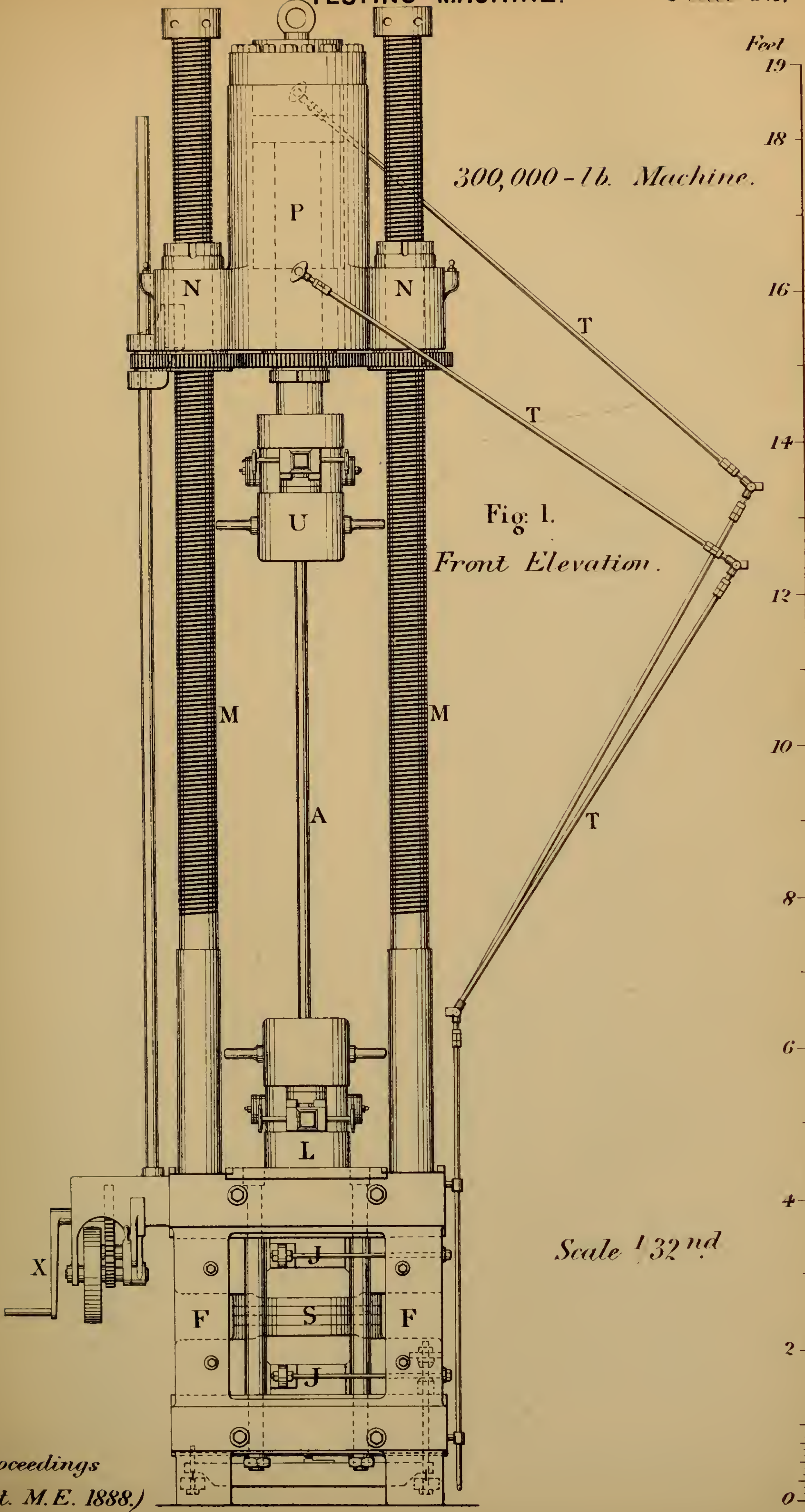


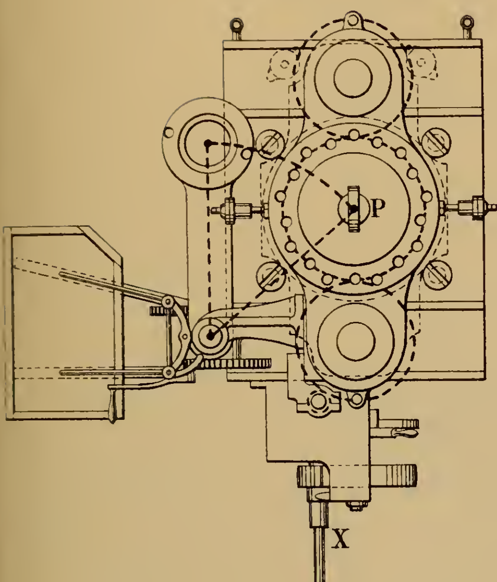
Fig: 1.
Front Elevation.

Scale 1/32nd

300,000-lb. Machine.

Scale 1/32nd.

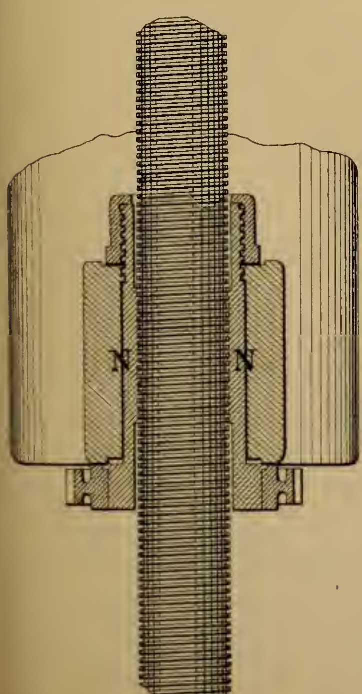
Fig. 3. *Plan.*



Adjusting Nut.

Fig. 4. *Vertical Section.*

Scale 1/16th.



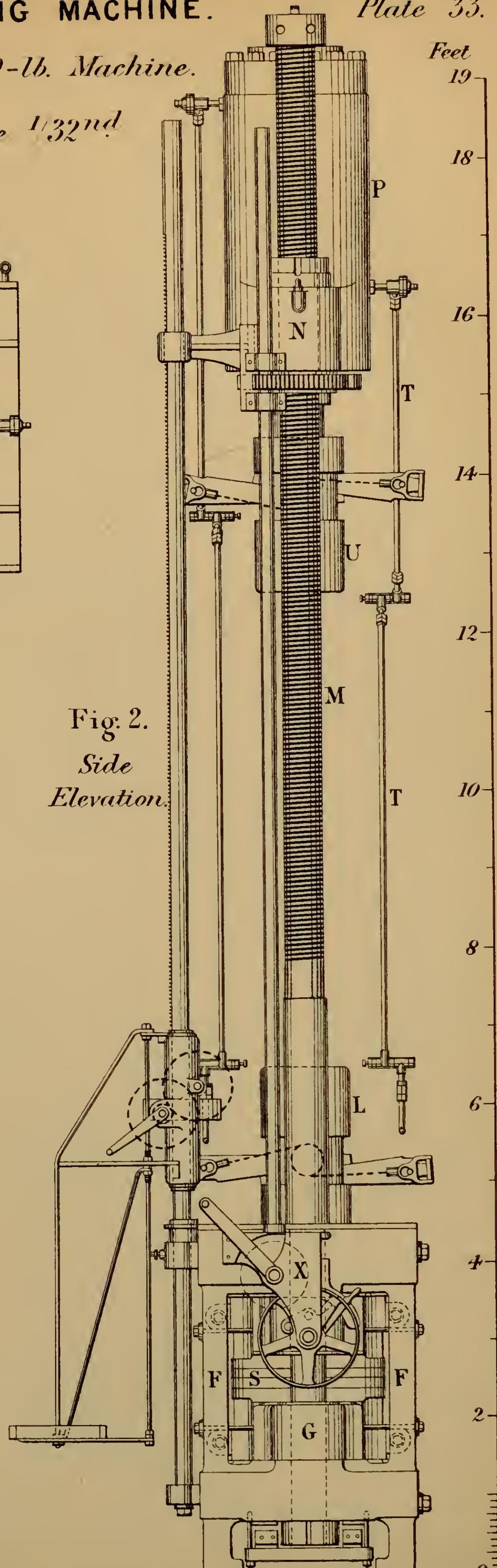
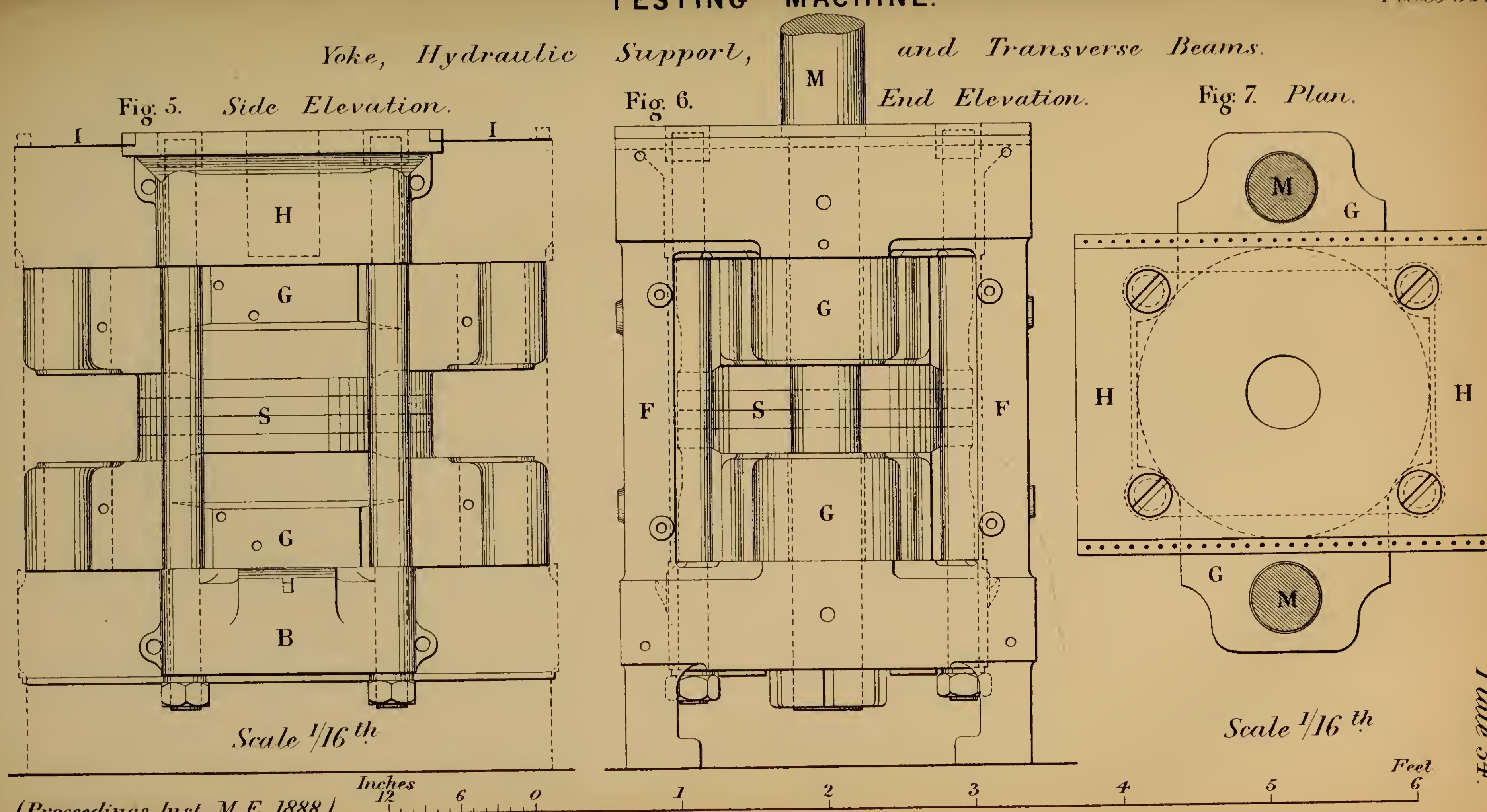


Fig. 2. *Side Elevation.*

TESTING MACHINE.

Yoke, Hydraulic Support, and Transverse Beams.

Fig. 5. *Side Elevation.* Fig. 6. *End Elevation.* Fig. 7. *Plan.*



Scale 1/16 th. *Scale 1/16 th.*

(Proceedings Inst. M. E. 1888.)

Plate 34.

Hydraulic Support.

Scale 1/6th

Fig. 8. *Plan.*

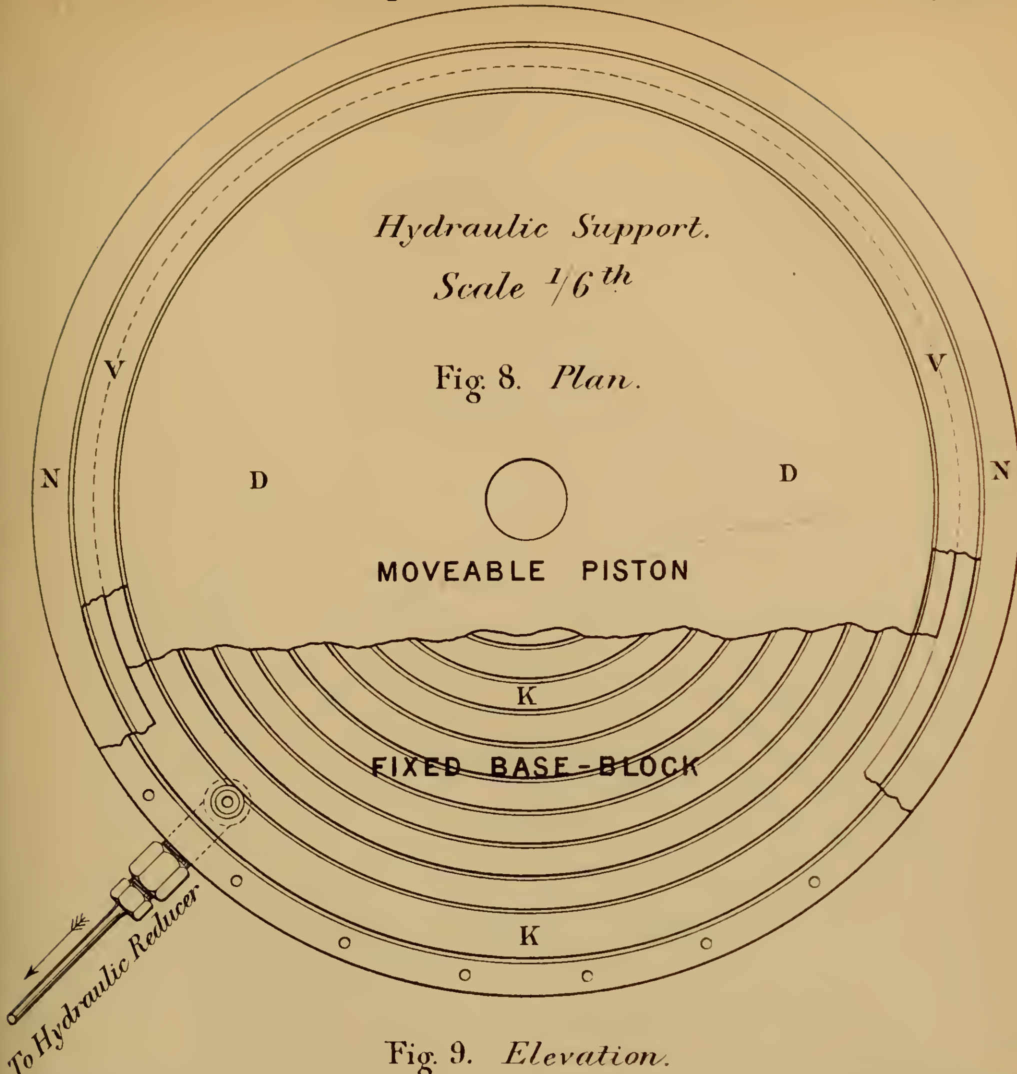


Fig. 9. *Elevation.*

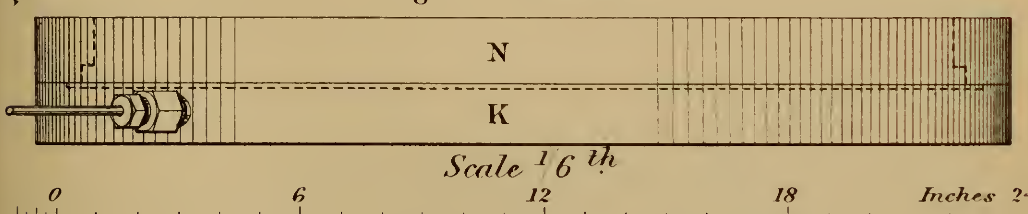
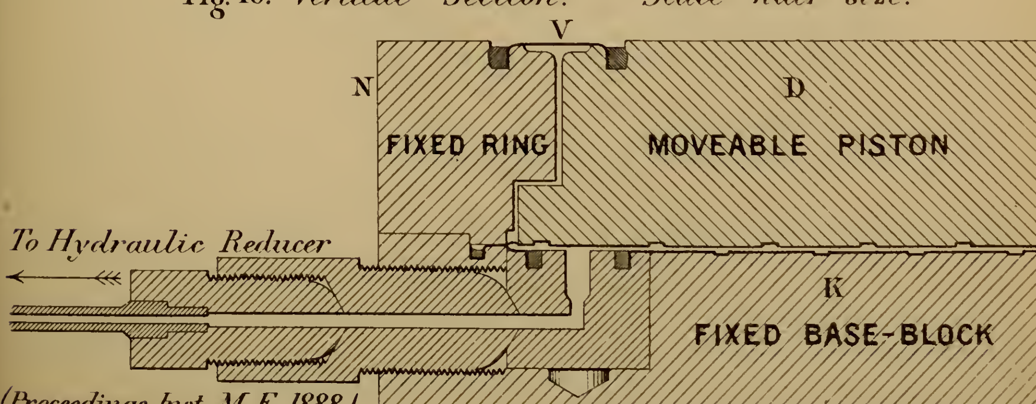


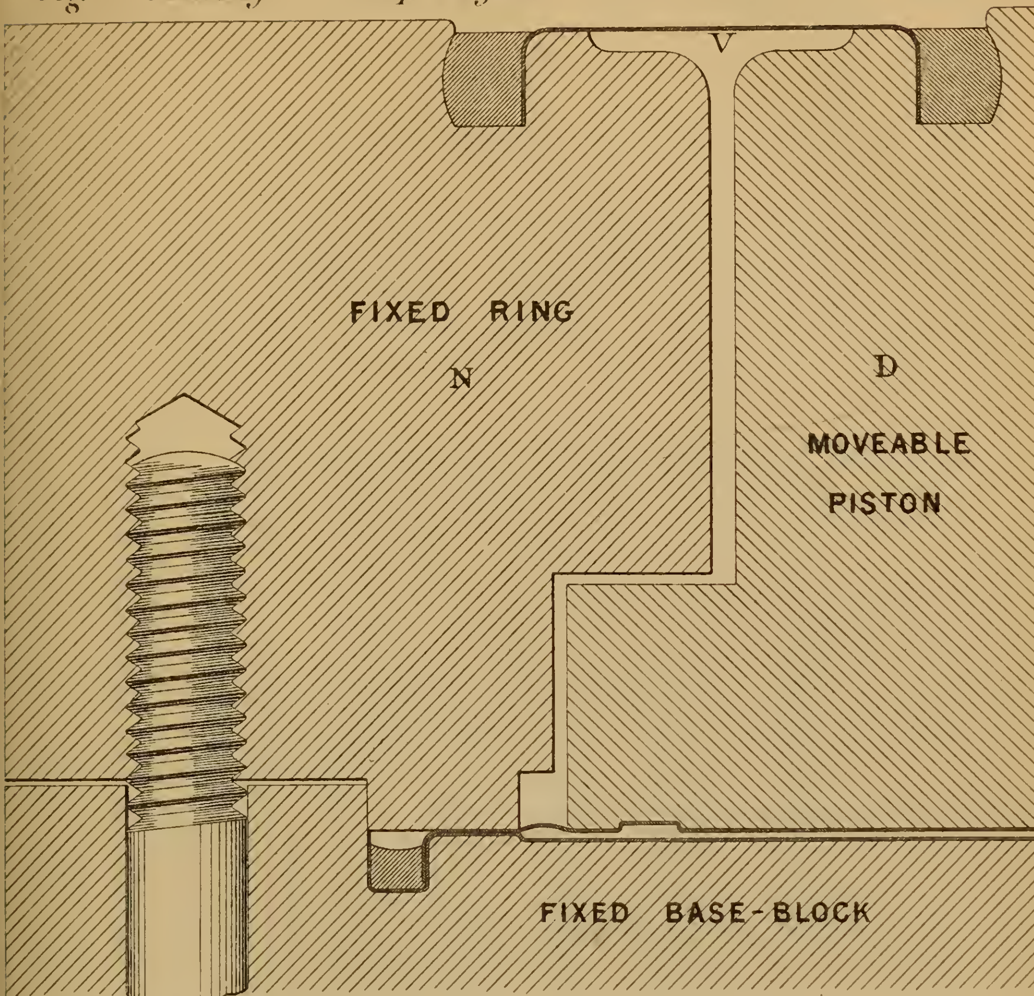
Fig. 10. *Vertical Section.* *Scale half size.*



(Proceedings Inst. M. E. 1888.)

Hydraulic Support.

Fig: 11. *Sealing of Diaphragms. Scale double full size.*



Hydraulic Reducer. Fig: 12. *Vertical Section.*

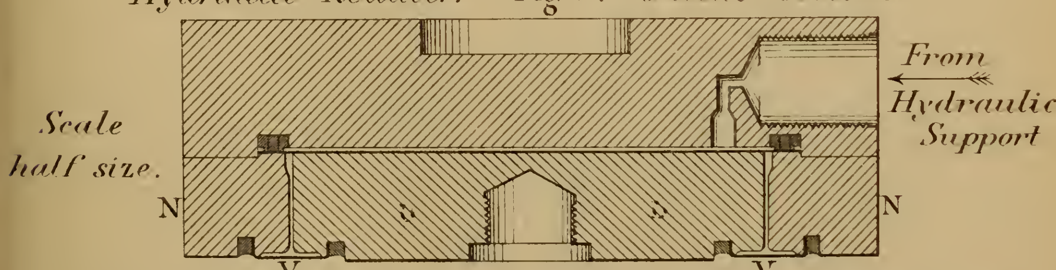
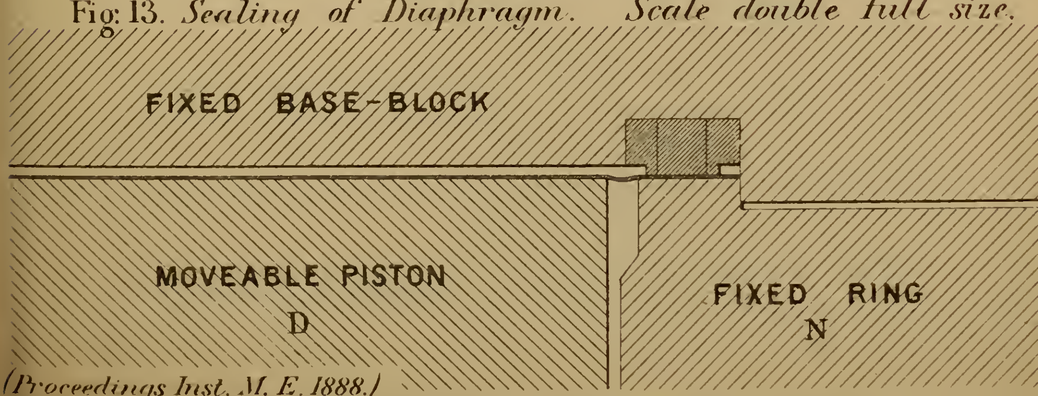
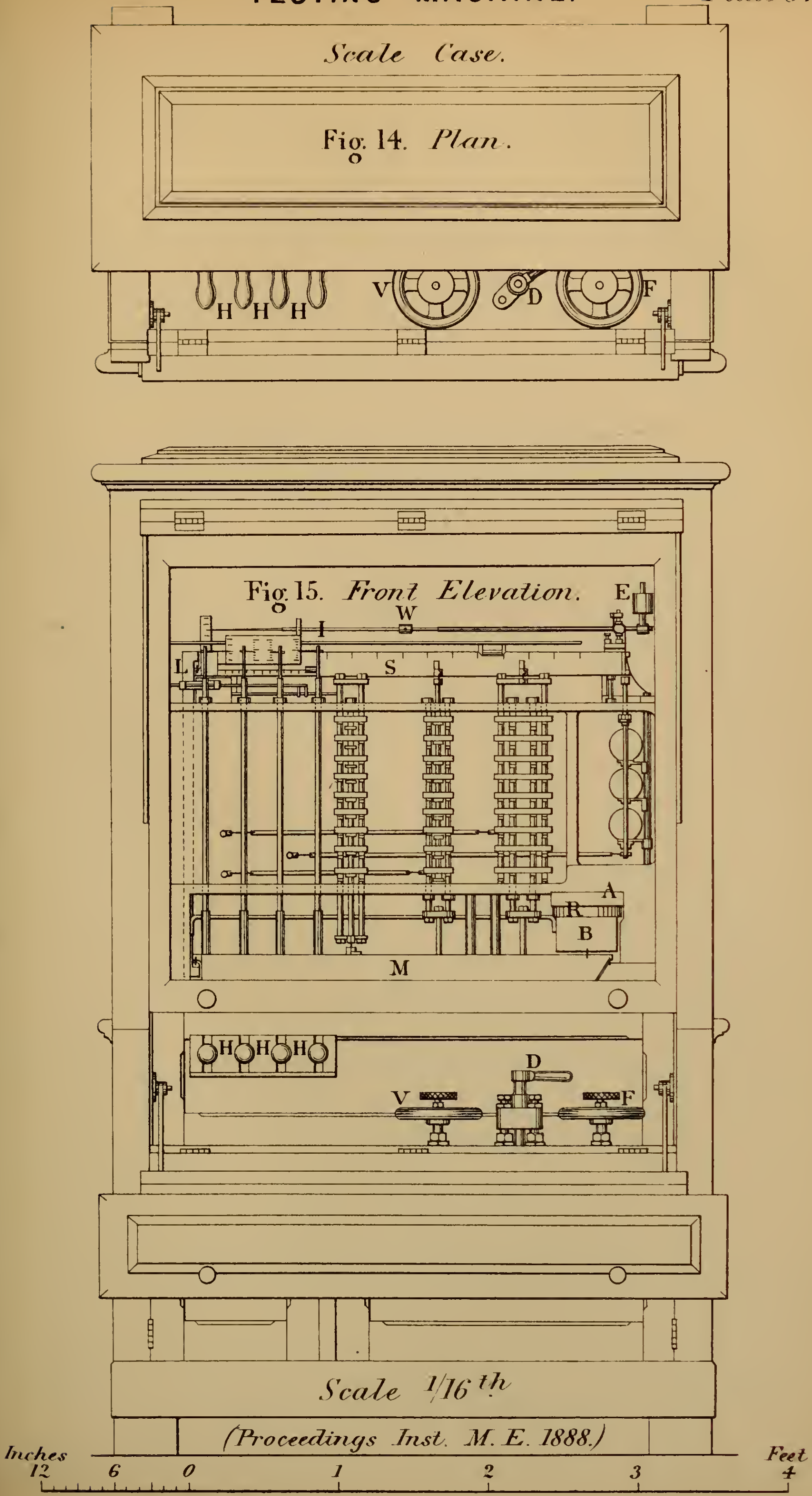


Fig: 13. *Sealing of Diaphragm. Scale double full size.*



TESTING MACHINE.

Plate 37.



Arrangement of Levers in scale case.

Fig. 16. *Plan.*

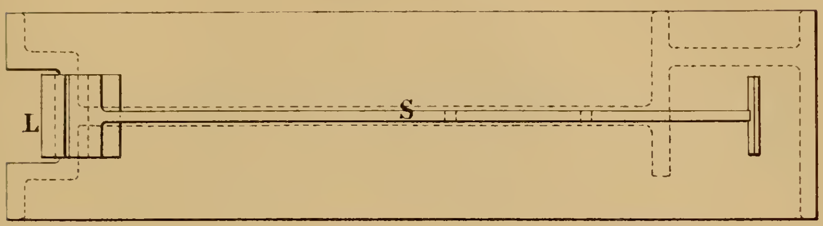
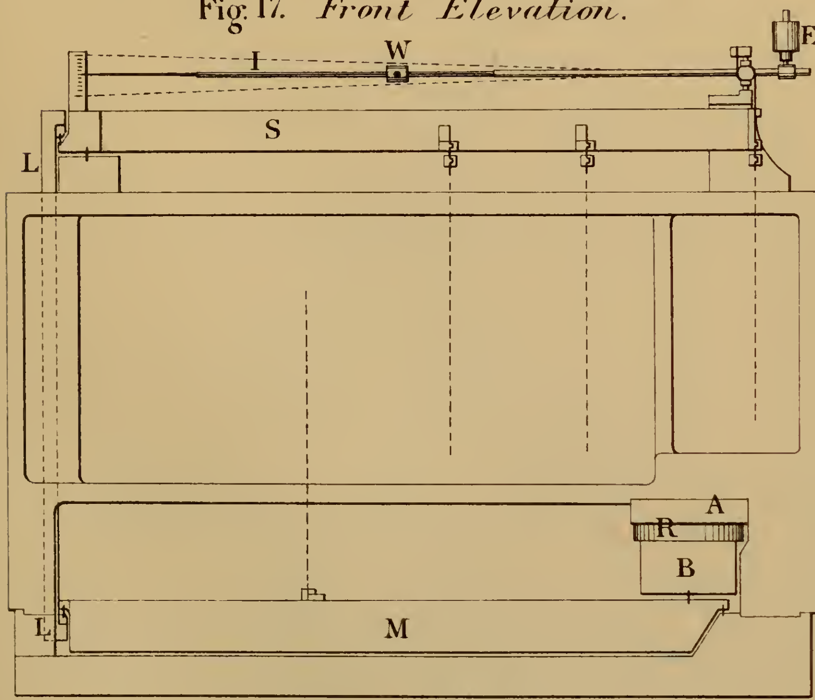
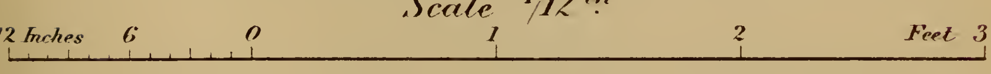


Fig. 17. *Front Elevation.*



Scale 1/12th.



Fulcrum – Plate of main lever.

Fig. 18. *Transverse Section.*

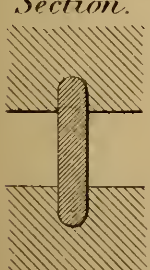
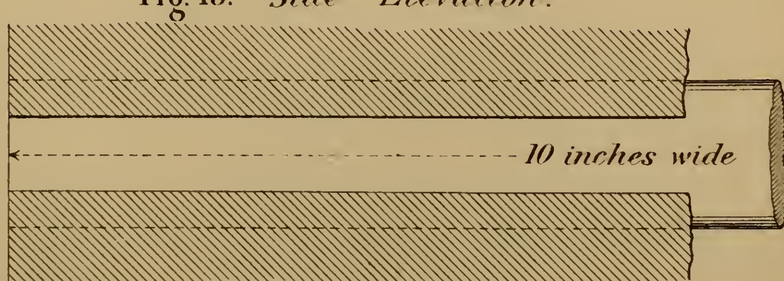


Fig. 19. *Side Elevation.*



Scale double full size.

TESTING MACHINE. *Plate 39.*

Tension Holder.

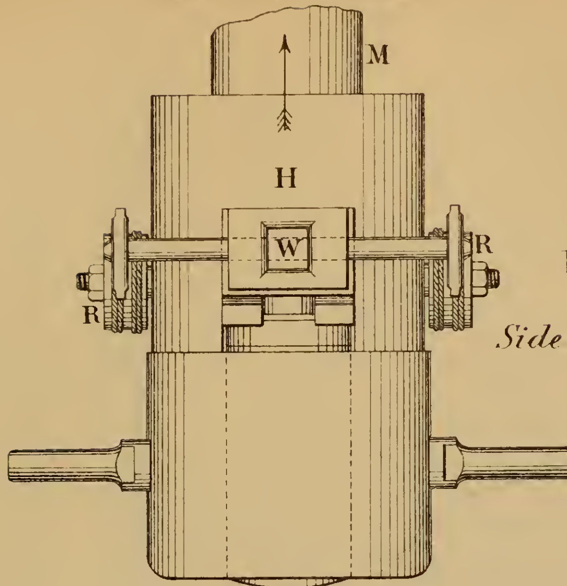


Fig: 20.

Side Elevation.

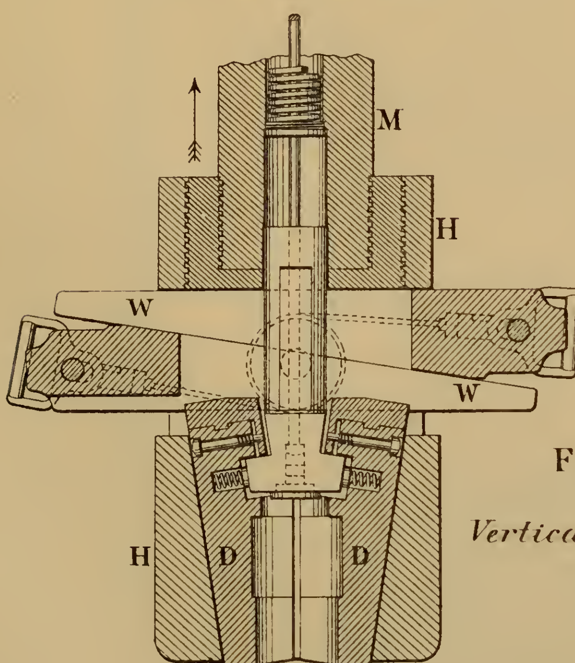


Fig: 21.

Vertical Section.

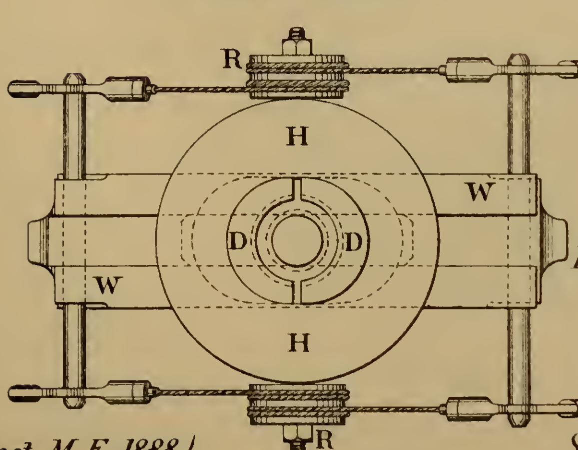


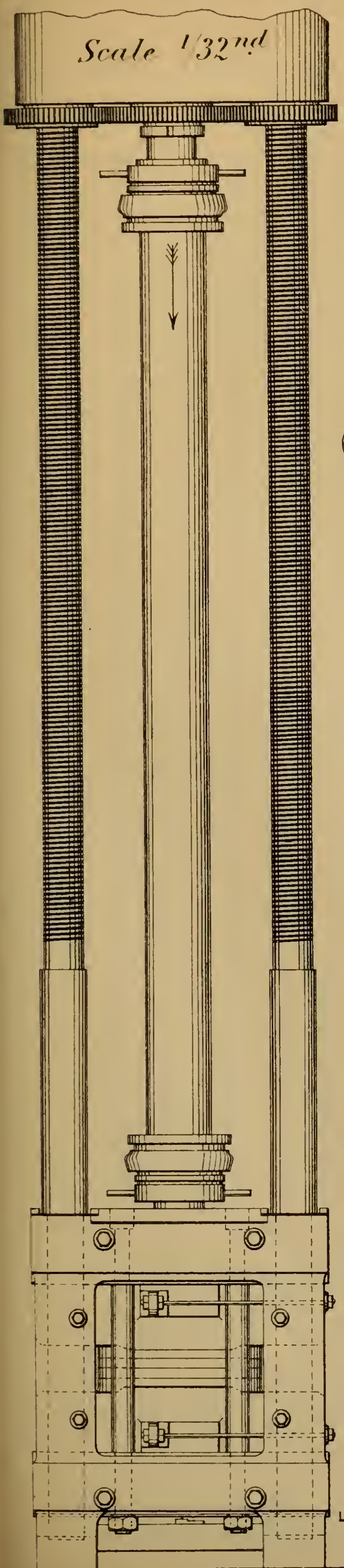
Fig: 22.

Plan inverted.

Scale 1/12th

Inches 12 6 0 1 2 Feet.

Fig. 23. *Front Elevation.*



Compression Tests.

Compression Holder. Scale 1/8th

Fig. 24. *Plan.*

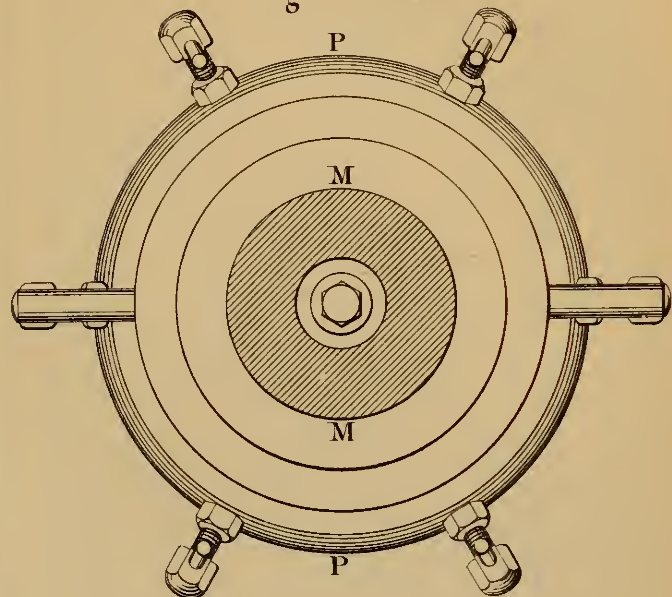
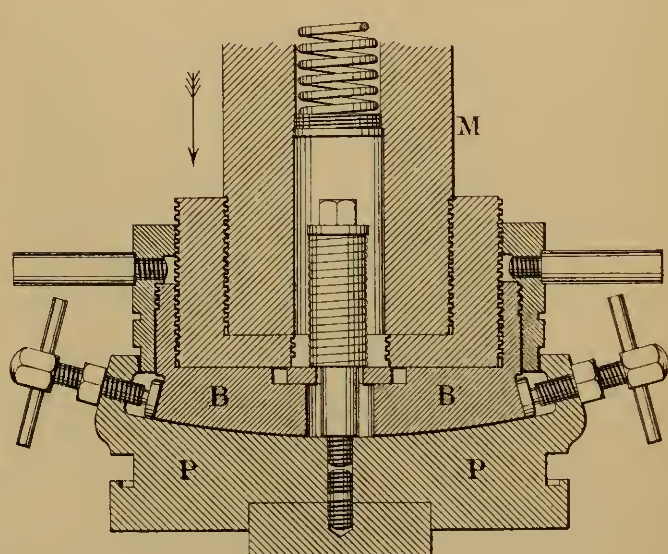
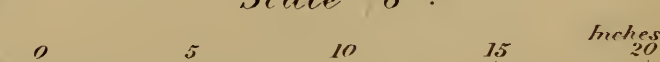


Fig. 25. *Vertical Section.*



Scale 1/8th



TESTING MACHINE.

Transverse Tests.

Fig. 26.

End Elevation.

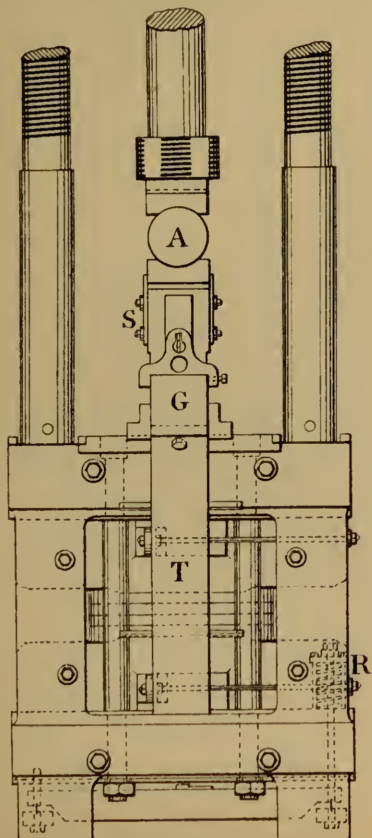
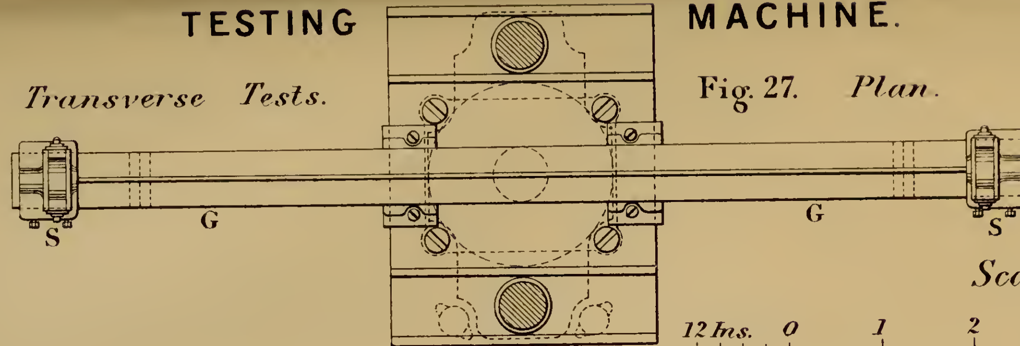


Fig. 27. Plan.



Scale 1/32nd

12 Ins. 0 1 2 3 4 5 6 Feet 7

Fig. 28. Side Elevation.

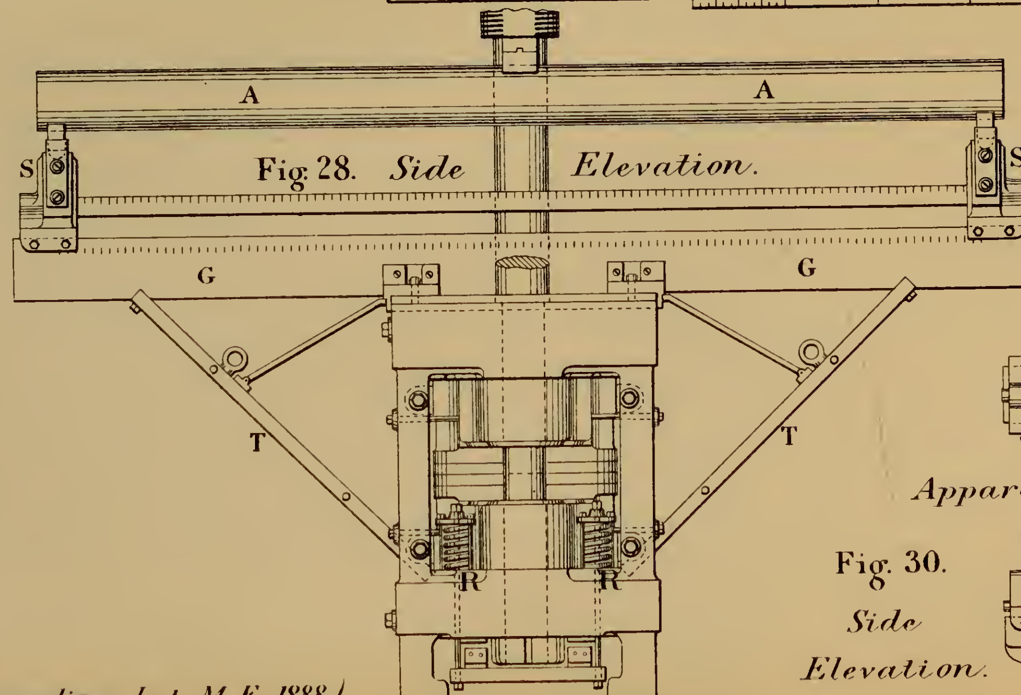
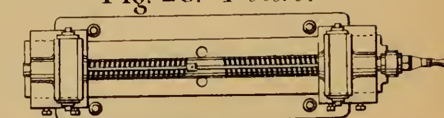


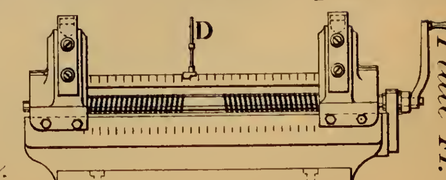
Fig. 29. Plan.



Apparatus for short specimens.

Fig. 30.

Side Elevation.



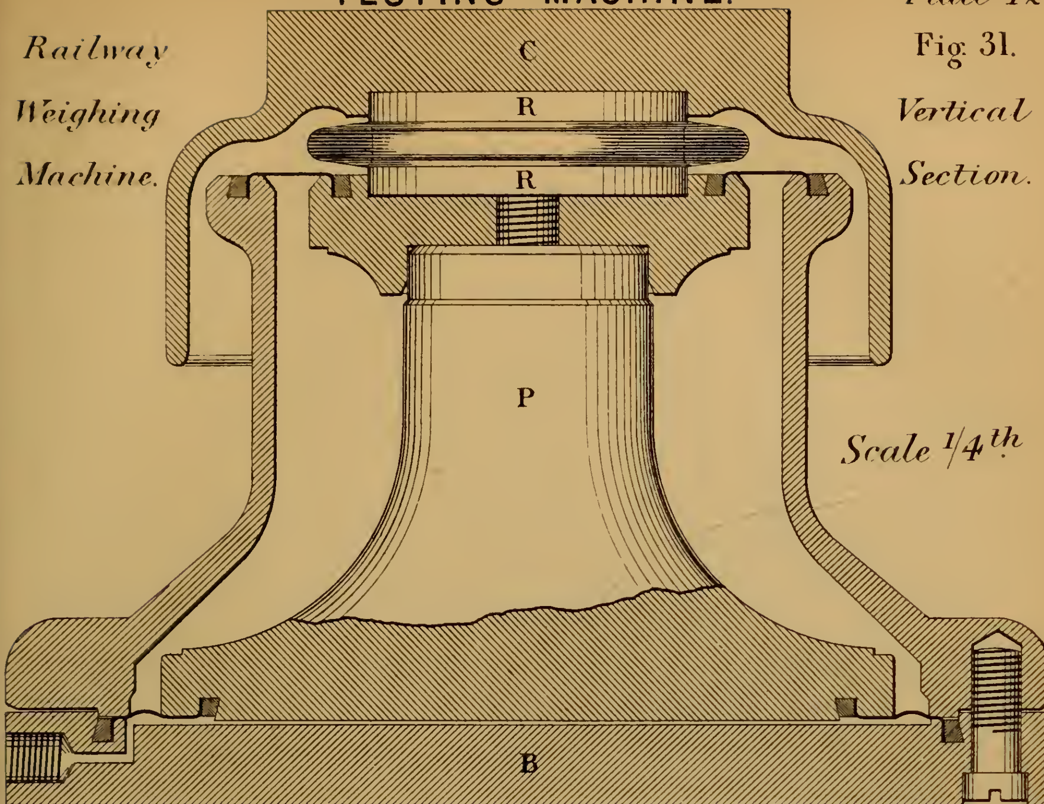
(Proceedings Inst. M. E. 1888.)

Plate 41.

Railway Weighing Machine.

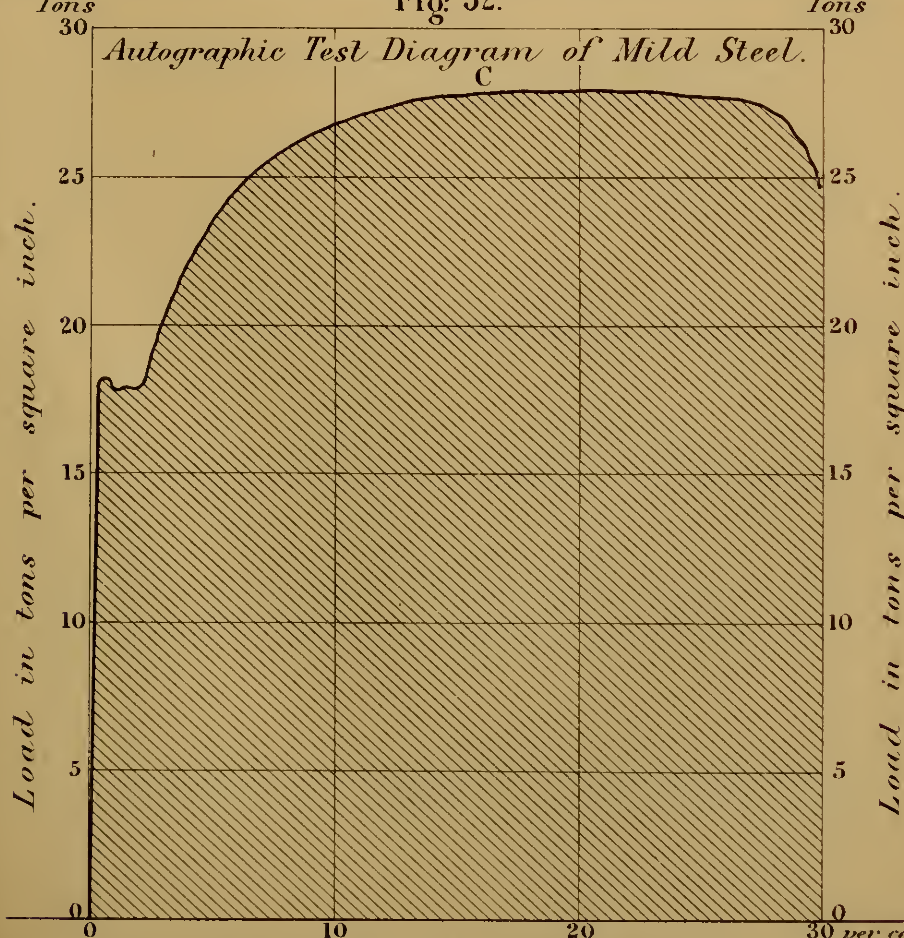
Fig: 31.

Vertical Section.



Scale 1/4th.

Fig: 32.



Autographic Test Diagram of Mild Steel.

(Proceedings Inst. M. E. 1888.)

Institution of Mechanical Engineers.

PROCEEDINGS.

July 1888.

The Summer Meeting of the Institution was held in Dublin, commencing on Tuesday, 31st July 1888, at Ten o'clock a.m.; Edward H. Carbutt, Esq., President, in the chair.

The President and Council and Members were received in the Examination Hall of Trinity College, by the Right Honourable the Earl of Rosse, Chairman, and other members of the Local Committee.

The Earl of Rosse said that on the part of the Local Reception Committee he had great pleasure in welcoming the President and Members of the Institution of Mechanical Engineers, and in expressing the hope that they would enjoy their present visit to the city of Dublin. Although of course in this agricultural portion of the kingdom manufactories and engineering works were in general on a comparatively small scale, he had no doubt that there would be enough in them to interest the Members for a few days; and at the end of their stay here they would also see many signs of advancement in the northern part of the island. The city of Dublin was much indebted to the Institution for this visit, all the citizens being anxious to get new ideas from other parts of the kingdom. If they had not the benefit of occasional visits from such bodies as the Institution of Mechanical Engineers, they would not be so well aware of what was going on in the engineering and scientific world.

The President was sure he should be expressing the feeling of all the Members of the Institution of Mechanical Engineers in

(The President.)

tendering their hearty thanks to the Earl of Rosse and the Reception Committee for the cordial welcome extended to them and the admirable programme arranged for their visit. They were all practical men, though not so eloquent as their Irish friends. The famous educational establishments in Dublin and elsewhere in Ireland had proved so successful that all over the world engineers were met with who had been educated here. The Institution of Mechanical Engineers had therefore a close affinity with Ireland. During their present stay there would be many opportunities of seeing the different works in the country, and of observing what Ireland had done for herself; and when they had finished their visit he was sure they would be delighted that they had come to this meeting, and would be yet more grateful to the Committee for having done so much to promote their convenience and enjoyment.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following forty-four candidates were found to be duly elected:—

MEMBERS.

Asplan Beldam,	London.
Richard Birtwistle,	Manchester.
Charles Septimus Bruff,	Secunderabad.
Frederick Henry Butter,	Woolwich.
John Joseph Cook,	St. Helen's.
George Crowe,	Cardiff.
George Manners Dickson,	Calcutta.
William Bromley Featherstone,	Dundalk.
Edward John Forster,	Birmingham.
Edward Henry James Gaze,	Glasgow.
John Goff,	Burton-on-Trent.
George Harrison,	Manchester.
Thomas Hosking,	London.

GEORGE HUXLEY, ...	Manchester.
JOSEPH INGLEBY, ...	Manchester.
WILLIAM JOHNSON, ...	Leeds.
FREDERIC KERSHAW, ...	Argentine Republic.
BALDWIN LATHAM, ...	London.
Sir BRADFORD LESLIE, K.C.I.E., . .	London.
Major-General EARDLEY MAITLAND, R.A.,	Woolwich.
BUNJI MANO, ...	London.
HENRY JAMES MARTIN, . . .	Swansea.
FARQUHAR MATHESON McLARTY, . .	Penang.
THOMAS PARKER, JUN., . . .	Manchester.
CHARLES EDMUND PEEL, . . .	Swansea.
NORMAN PIRRIE, ...	Berlin.
TSUNETA SHIN, ...	London.
HARRY FRANK STANLEY, . . .	London.
WILLIAM CHARLES STIFF, . . .	Birmingham.
JAMES STRACHAN, ...	Nottingham.
PHILIP ALEXANDER THOMAS, . .	London.
ROBERT SAMUEL THORNTON, . . .	Etawah, India.
ROBERT ERNEST TODD, . . .	Argentine Republic.
WILLIAM HENRY WAISTER, . . .	Wolverhampton.
PETER WILLIAM WILLANS, . . .	Thames Ditton.

ASSOCIATES.

HAROLD BROWN, ...	London.
CHARLES EDWARD CHRIMES, . .	Rotherham.
ROBERT CECIL PEAKE, . . .	Bletchley.
THOMAS TUCKER, ...	Gateshead.

GRADUATES.

HERBERT HENRY COX, . . .	Falmouth.
JOSEPH LETCHFORD, ...	London.
DAVID LOFTS, ...	London.
RICHARD WHICHELLO, . . .	Rio de Janeiro.
EDWARD YATES, ...	Stony Stratford.

The PRESIDENT said he had the highly gratifying announcement to make that the honorary degree of "Master in Engineering" had been conferred by the University of Dublin upon two Past-Presidents of this Institution, namely Sir Lowthian Bell, Bart., and Mr. Ramsbottom. This was the highest engineering degree, and had been conferred *honoris causâ* in only six previous instances. It was thus a very high honour which had been paid to two of the Past-Presidents of the Institution, each of whom was worthy of a distinction so rarely conferred, both of them being eminent engineers who had made their mark in the world and had done good work. The Members he was sure would concur with himself in recording their sense of the honour which the University of Dublin had conferred upon their Past-Presidents. The Council had directed a letter of congratulation to be addressed to each, on their having received the honour of this distinction.

The PRESIDENT then delivered his Address: after which the following Papers were read and discussed:—

Description of a Balanced or Automatic Sluice for Weirs; by the Right Honourable the EARL OF ROSSE, F.R.S.

On the latest improvements in the Clock-Driving Apparatus of Astronomical Telescopes; by Sir HOWARD GRUBB, F.R.S., of Dublin.

At One o'clock the Meeting was adjourned to the following morning.

The ADJOURNED MEETING was held in the Examination Hall of Trinity College, Dublin, on Wednesday, 1st August 1888, at Ten o'clock a.m.; EDWARD H. CARBUTT, Esq., President, in the chair.

The following Papers were read and discussed:—

Description of Tramways and Rolling Stock at Guinness's Brewery; by Mr. SAMUEL GEOGHEGAN, Engineer to the Brewery.

Description of the Frictional Gearing used on a double Steam Dredger in the Port of Dublin; by Mr. John Purser Griffith, President of the Institution of Civil Engineers of Ireland.

Description of the Compound Steam Turbine and Turbo-Electric Generator; by the Honourable Charles A. Parsons, of Gateshead.

Shortly after One o'clock the Discussion upon the last Paper not having been completed was adjourned; the publication of this Paper is deferred for the completion of the Discussion. The two remaining Papers announced for reading and discussion were adjourned to subsequent meetings.

The President proposed the following Votes of Thanks, which were passed by acclamation:—

To the Provost and Senior Fellows of Trinity College for the facilities and accommodation they have again so obligingly afforded for holding the present Meeting of the Institution in the buildings of the College.

To the Reception Committees in Dublin and Belfast, for the highly acceptable and hospitable arrangements they have made for welcoming and entertaining the Members of the Institution during their visit to Ireland; and particularly to their Executive Officers, by whose exertions the whole of the arrangements have been so ably matured.

To the Proprietors of the numerous Engineering and Manufacturing Works and other Establishments which the Members have been so liberally invited to visit in connection with the Meeting.

To the Chairmen and Directors of the Great Southern and Western Railway, the Great Northern Railway of Ireland, the London and North Western Railway, the Belfast and Northern Counties Railway, the Belfast Steamship Co., the Dublin United Tramways Co., and the Dublin and Lucan Steam Tramways Co., for their kindness in arranging special facilities for the convenience of the Members in the various Excursions.

To the Senate of the Royal University of Ireland for their kindness in granting the use of their large Halls for the Institution Dinner.

The Meeting then terminated. The attendance was 179 Members and 88 Visitors.

ADDRESS BY THE PRESIDENT,

EDWARD H. CARBUTT, Esq.

Gentlemen,—The Institution of Mechanical Engineers, in addition to their meetings in London for the reading and discussion of papers on mechanical subjects, devote their Summer Meeting to visiting some city or district where by the interchange of ideas the Members may receive valuable information, and at the same time, it is hoped, impart knowledge which may benefit the district visited. Two years ago we held our Summer Meeting in London, the capital of the empire; and at that meeting we received the Belgian Association of Engineers. Last year we visited Edinburgh, the capital of Scotland. This year we are honoured by being received in Dublin, the capital of Ireland. Next year we purpose visiting a foreign country, and going to Paris for the International Exhibition. Mechanical ingenuity appeals to us wherever found; it requires no translation from a foreign tongue, but is equally understood by engineers of all countries.

At these Summer Meetings a large proportion of our time is devoted to visiting the engineering works of the district. In London we spent some time in visiting works for the manufacture of warlike stores, namely the national gun factory at Woolwich and the small-arms factory at Enfield.

In Scotland our attention was mainly devoted to the Forth and Tay bridges, the Isle of May electric lighthouse, and the waterworks. Here in Ireland you intend showing us your harbours, both in Dublin Bay and in Belfast Lough; and in addition, two of the largest establishments of their kind perhaps in the world, namely Guinness's porter brewery in Dublin, and the shipbuilding and marine-engine works of Messrs. Harland and Wolff in Belfast.

We are also invited to visit the principal roller flour mills, of which so many large and flourishing examples exist in Dublin and the neighbourhood; and considering what an important industry this is in the district, the paper promised by Mr. Simon on this interesting subject ought to give rise to a good discussion. An extremely interesting visit will also be that to the optical and mechanical works of Sir Howard Grubb, where, in addition to other ingenious appliances, will be seen the clock-driving apparatus for astronomical telescopes which he has succeeded in controlling by electricity with such accuracy as to allow of photographing stars, and of which we are promised a description in his paper on this subject. These and other numerous attractions form the magnet which has now drawn us with irresistible force to visit Ireland again after an interval of twenty-three years.

On the occasion of the former Meeting of this Institution in Dublin in 1865 under the presidency of the late Mr. Robert Napier, we enjoyed the advantage of meeting in Trinity College, as by the renewed kindness of the college authorities we do again on the present occasion. The Papers then read were all of them more or less directly connected with the industrial interests of Ireland. The first was on "Machinery employed in the Preparation and Spinning of Flax," by Mr. Thomas Greenwood of Leeds, who had had large experience in the manufacture of machinery for that purpose. A description was given of the "Manufacture of Compressed-Peat Fuel" at Derrylea; and a day's excursion was made to the peat works, to see the whole of the machinery and process of manufacture, which was then being carried out on an extensive scale. In spite however of the admirable nature of the machinery and the simplicity of the method followed, and notwithstanding the very excellent quality of the compressed-peat fuel produced, this manufacture, which it was hoped would meet with extensive and profitable application to the bogs of Ireland, unfortunately proved unsuccessful commercially, and was shortly afterwards abandoned. Dried peat is now largely used for bedding for horses and cows, under the name of moss litter. An interesting description of the "Bank-note Printing Machine," devised and employed by himself

at the Bank of Ireland, was given by the engineer to the Bank, Mr. Thomas Grubb; by whose son and successor, Mr. Henry T. Grubb, we are invited to visit the Bank again on the present occasion, in order that any Members who did not then see this admirable machine may have the opportunity of doing so now. Two other papers described the "Vartry Water Works" and the "Rock-Boring Machine" employed in the tunnel through which the water supply was brought to Dublin; and to these works a day's excursion was made under the guidance of the late Sir John Gray. Excursions were also made to the Lead Smelting Works of the Mining Company of Ireland at Ballycorus, and to the Connorree Copper and Sulphur Mines in the Vale of Ovoca.

Instead of confining my remarks to purely mechanical subjects, perhaps you will allow me to bring to your notice some statistics which relate to the whole of Ireland, and to take if possible a general view of the population and their employment, &c. Unfortunately it is difficult to arrive at an exact appreciation of the manufactures of Ireland, as no account of the export and import trade is kept. Each seaport no doubt keeps an account of its own import and export tonnage, but there are no separate government returns for the whole island. In 1865 the tonnage of vessels which entered Irish ports was 4,476,000, and of those cleared outwards 2,997,000; in 1886 the corresponding figures were respectively 5,936,000 and 3,946,000. In reference to the population, we have of course the census returns; but I am indebted to a very interesting paper by Mr. Leonard Courtney, M.P., in the 'Nineteenth Century,' on the "Swarming of Men," for the following particulars. While in Great Britain every successive census has shown an increase in population, in Ireland there has been a decrease; so that the population of Ireland, which amounted to over eight millions in 1841, was under five millions in 1887:—

Year .	1841	1851	1861	1871	1881	1887
Population .	8,175,000	6,552,000	5,799,000	5,412,000	5,175,000	4,837,000

And to the middle of the present year the population is estimated at 4,777,515. The births have exceeded the deaths, but the balance

has been taken away by emigration. Mr. Courtney shows that the tendency of all population, not only in this country, but in Sweden and Italy, is to leave the agricultural districts, and either crowd into the towns or emigrate to where land is cheaper. Dr. T. W. Grimshaw, the Registrar General of Ireland, has kindly furnished the following figures of the increasing town population in Ireland, while the rural are decreasing numbers:—

1841	1851	1861	1871	1881
1,144,000	1,227,000	1,140,000	1,201,000	1,246,000

The large number in the towns in 1851 was owing to the famine of 1847. In England and Wales the inhabitants of towns have increased five-fold since 1801, while the inhabitants of the country districts have increased only seventy-five per cent.; with the result that in England the town population represents two-thirds of the total population, but in Ireland only one-fourth of the total population live in towns containing above 2,000 inhabitants. In England, owing mainly to her mineral wealth, the people have become manufacturing, and are thus able to support all the population which leaves the country districts and crowds into the towns. On the other hand Ireland is mainly an agricultural country, owing partly to absence of an abundant supply of minerals, and partly to the political action which in years gone by killed her manufacturing trade in woollen goods.

It is estimated that agricultural industry supports in England 13·2 per cent. of the population, in Scotland 14·0 per cent., and in Ireland 49·5 per cent. of the population: whence it is seen that Ireland is mainly dependent on her agriculture. The average number of persons belonging to each class of population in 1881 was as follows, per thousand:—commercial 14; agricultural 193; industrial 134. The towns not having manufacturing industry sufficient to tempt the people from the land, they remain where they were born, so that barely one-tenth of Irish-born persons living in Ireland live out of the county in which they were born. If they leave their birthplace at all they leave the country altogether, as the towns have no better chances of livelihood to offer them. In Kerry and Mayo out of every 100 persons 96 were born

there. A curious fact mentioned by Mr. Courtney is that, although the inhabitants of Ireland not Irish-born are relatively few, they have been steadily increasing, while the native inhabitants have been decreasing. There are three times as many English and Scotch and more than four times as many foreigners in Ireland now as there were in 1841. It is remarkable that while Irishmen are leaving the country outsiders can find means of subsistence here. The probable explanation is that the unskilled labour is leaving the country, and that those who come in are skilled workmen. The emigration has been immense: in the fifteen years 1872–86 no less than 1,030,000 persons left the island.

The following table shows the occupations of the population divided under six heads, comparing the years 1871 and 1881, but the classification was much modified between these two dates:—

Occupation.	1871.	1881.
Professional	154,100	198,684
Domestic	387,681	426,161
Commercial	75,618	72,245
Agricultural	985,790	997,956
Industrial	929,767	691,509
Indefinite and Unproductive	2,879,421	2,788,281
Total population	5,412,377	5,174,836

The large increase here seen in the professional class is due no doubt to the good work done by the colleges in Ireland. For the decrease in the commercial class I do not see how to account. The numbers employed in agriculture are practically the same in 1881 as in 1871. Only $2\frac{1}{2}$ per cent. of the total acreage under cultivation in Ireland is devoted to flax, which produces on an average of ten years 20,762 tons annually. Foreign flax is imported into the United Kingdom to the average extent of 82,911 tons annually. The Flax Supply Association of Belfast are doing good work in encouraging the growth of flax; and I would recommend the perusal of their annual report to those especially interested in this trade. The number of power looms in Ireland was 8,187 in 1864, and 24,300 in 1885; the number of spindles in Ireland was 592,981 in 1861, and 817,014 in 1885.

As already pointed out, agriculture is the main industry of Ireland. To give an idea of her agricultural wealth I quote the number of live stock in Ireland in 1865 and 1887 :—

	Horses.	Cattle.	Sheep.	Pigs.
In 1865 . .	548,339	3,497,548	3,694,356	1,305,953
In 1887 . .	557,405	4,157,404	3,377,826	1,408,456

It will be seen that Ireland is richer now in the number of horses, cattle, and pigs, than on our last visit in 1865. I am not aware that there are any correct records of the total value of the exports of agricultural produce; but its importance may be gathered from the following figures for 1886 furnished in the "Fair Trade Gazette" by Mr. Tallerman in regard to one portion, namely the cattle imports into Great Britain from Ireland, which are considerably more than from all the rest of the world put together :—

	Cattle.	Sheep.	Pigs.	Total.
British imports from Ireland	719,673	734,213	421,285	1,875,171
Foreign and colonial imports	319,571	1,038,956	21,351	1,379,878
Excess of animals from Ireland	400,102		399,934	495,293

There is thus an excess of 400,000 cattle from Ireland, and the same of pigs; and a net excess of 495,000 animals of all three kinds imported from Ireland, as compared with the foreign and colonial imports into Great Britain. The following are given by Dr. Grimshaw as the exports of cattle, sheep, and pigs :—

	Cattle.	Sheep.	Pigs.
1865	246,734	332,831	383,452
1875	595,318	917,979	463,618
1887	669,253	548,568	480,920

The foreign meat supply of England comes very largely, not as live cattle, but as dead meat of the value of £13,250,000 annually. It is killed in New Zealand, Australia, and South America, and shipped here in frozen chambers. Depend upon it that it will not be long before the fat cattle are killed in Ireland, when proper arrangements are made for keeping the meat cool in transit. Mr. Tallerman states that a live ox sent by rail

and driven to the butcher loses 24 lbs. weight of meat by three days' travel. In addition to this gain of meat, the cost of carriage would be less, and the poor cattle would be spared the torture of a sea voyage. What I feel however is that, while every attention should be given to this the most important part of the trade of Ireland, it holds good in agriculture as well as in manufactures that attention to the smaller articles of trade often ensures large results. Just as Fox's patent for umbrellas has earned more money than Nasmyth's steam-hammer, so in agriculture, if more attention were devoted to cheese, butter and cream, eggs and poultry, Ireland would take a large part of the money which England at present pays daily to France and Denmark for these articles. The number of poultry in Ireland in 1865 was 10,681,955; in 1888 the number returned was 14,437,257.

In agricultural machines having for their object the saving of manual labour the following increase has taken place:—

	Total.	Churning Machines.	Reaping and Mowing Machines.
1865	24,958	848	1,085
1886	30,364	2,653	9,014
Increase	5,406	1,805	7,929

With regard to the encouragement of the butter industry, no man has done better work for Ireland than Canon Bagot. In his "Hand-book on Dairy Factories, Creameries, and Home Dairying," he points out that if practical information were disseminated among dairy farmers we should eventually keep at home the greater part of the £14,000,000 at present paid annually to foreign countries for butter. He strongly recommends co-operative dairying, as it can best be carried out by the factory system. He has erected a model dairy at the Irish Exhibition in London, which every one interested in this subject should see. He has also established several factories in Ireland. If butter making is to succeed, it must be by the extension of the factory system, and the employment of the best machinery for creaming, churning, and mixing the butter. Besides, the manager of these factories must gain more experience

by giving his undivided attention to it, than each separate farmer can by giving only part of his attention. The farmer will thus be able to give undivided attention to his farm. In the butter factory the milk is at once creamed by De Laval's or Petersen's centrifugal separators, and is immediately converted into butter, which is fresher, will keep longer, is purer, and ought to cost less, than that made on the old system of waiting 24 to 48 hours for the cream to rise. From 15 to 20 per cent. more cream can be got by the use of the separator, which means that a farm of 30 cows, producing 30 lbs. of butter per day by hand skimming, will yield 34 lbs. to 36 lbs. by using the separator. More than a hundred of these machines are now in use in Ireland. A description of the De Laval separator was given to this Institution in 1882 (Proceedings page 519). Sir Lyon Playfair confirms Canon Bagot's opinion; for in an address delivered on 24th April last upon "Industrial Competition and Commercial Freedom" he says,—"the age of domestic manufactures is past. The conditions under which agricultural products can be manufactured by combination and machinery have been established. Creameries, butter factories, and cheese factories abroad succeed because they are conducted under manufacturing organisation, and not by isolated domestic producers."

In regard to eggs, we are now paying in England nearly £3,000,000 a year for our foreign supply of eggs, whereas thirty-two years ago we paid only £278,000. The present larger amount ought all to go into the Irish farmers' pockets, if properly looked after. I should like to commend to their consideration the able paper read before the Society of Arts on 7th December 1887 by Mr. P. L. Simmonds upon the "Chemistry, Commerce, and Uses of Eggs of various kinds." It is there shown that while the consumption is increasing, so that we now import 3¼ million eggs every working day, the price has also gone up: whereas in 1851 the price was 4*s.* 6*d.* per ten dozen, in 1887 it had risen to about 8*s.* wholesale.

The manufacturing prosperity of England is largely due to its mineral wealth. Unfortunately Ireland is not rich in minerals. The following figures of the mineral production, mainly in 1886,

show how small it is, only 8,164 persons being employed in mines and openworks:—

Coal raised in 1877	140,000 tons.	Value £.
„ „ „ 1886	105,563 „	42,225
Iron ore in 1886	108,350 „	17,953
Salt in 1886	31,000 „	14,150
Lead ore in 1886	241 „	1,928
Copper precipitate in 1886	26 „	283
Total produce in 1886 from mines		74,824
„ „ „ openworks—slate, stone, &c.		300,336

So you see only about 100,000 tons of coal are got per annum, and that not of the first quality. The Public Works Commissioners point out that coal is worked in Kilkenny within ten to twenty miles of three railways, and yet no branch line has been made to the mines; perhaps if railways were extended the mines might be more largely worked. The coal mining industry is not a growing one, as it will be noticed that since 1877 there has been a considerable decline. Mr. C. E. De Rance of the Geological Survey Office informs me that the 4-foot seam in the Kilkenny coalfield is almost worked out; this is the best coal and can be sold for 20*s.* per ton. Dr. Edward Hull, in his book on the "Coalfields of Great Britain," states that the quantity of coal raised in Ireland is comparatively small, and much below what it ought to be if all the coalfields were properly developed. He has taken every opportunity to encourage coal mining in Ireland. The districts of Tyrone and Antrim, he says, have considerable resources in mineral fuel; and he estimates the total available coal in Ireland at 182,280,000 tons. The seams are very thin, and it becomes a question how soon it will pay to work them. Only about 100,000 tons of iron ore are got every year, some of which is used for gas-purifying; the aluminous iron ore fetches 3*s.* per ton; the best 4*s.* per ton.

Concerning Irish railways we have many sources of information. A Commission under the Duke of Devonshire reported on railways, including Irish railways, on 7th May 1867, and reported against State purchase, and advised that amalgamation should be facilitated.

Then a Commission appointed by the Chief Secretary for Ireland reported on 30th April 1868 that if the Irish railways were all under one management £32,000 a year would be saved. And this year we have the report of the Public Works Commission under the chairmanship of Sir James Allport. Irish railways have been constructed partly by public money and only partly by private enterprise, £4,101,000 having been advanced to them by the government, of which £2,921,000 has been repaid. In addition to the one million still to be paid there is £115,000 for overdue interest. Comparing the railways at the date of our former visit with the present, we find that in 1865 there were seventeen railway companies with 1,838 miles of line, while in 1886 there were twenty companies with 2,615 miles; and in June 1888 there were 2,672 miles open. These figures of course do not include tram and light railways. The average increase has been 36 miles a year, and the total increase in train mileage and in gross earnings has been from 30 to 40 per cent. The net return on the paid-up capital in 1886 was slightly over 3½ per cent., or about the same as that earned in 1865. It would not be fair to compare the miles of railway in Ireland with the miles in England; but if compared with those in Scotland, there is one mile of line to every 12 square miles area and 1,800 inhabitants in Ireland, and one mile to every 10 square miles area and 1,200 inhabitants in Scotland. Remembering that Ireland is largely agricultural, she may be considered not badly supplied with railways; for in addition to the above total of railway lines there are the narrow-gauge and tram lines made under the tramways act of 1883, namely 162 miles opened or under construction, with a guaranteed capital of £676,000, and 141 miles sanctioned but not commenced, with a guaranteed capital of £581,000. Unfortunately the break of gauge to 3 feet has proved a disadvantage in these light railways.

It is satisfactory to note that Sir James Allport's Commission report that the condition of Irish railways has improved during the last twenty years in respect of finance, of permanent way, and of rolling stock. Their credit has improved, although it is not so high as that of English railways. The one thing in which no improvement

has taken place is the rates and fares, and in some cases these have increased. As Lord Emly pointed out in the House of Lords on 30th April last, the third-class traffic tripled in England in fifteen years, while it hardly made any progress in Ireland. Reduction in fares and greater facilities for third-class traffic would prove an immense boon to the poor Irish tenant-farmers. The management expenses are so great in Ireland that the fares cannot well be reduced. There are twenty boards of management with 313 directors for the Irish railways, with a total annual receipt of under £3,000,000; while in England the Great Western Railway with nearly the same number of miles of line is managed by nineteen directors, and has a total annual receipt of over £7,000,000. Not only are there so many directors in Ireland, but there is also separate management in every department on every separate railway; and what makes economy of working still more difficult is that many of the lines have separate stations in the same town, namely Dublin five passenger termini, Belfast three, Londonderry three, Waterford three, Cork five. In the locomotive department there must be considerable loss, in consequence of not getting a full mileage out of each engine on short lines. The result is that the working expenses in Ireland amount to 55 per cent. of the receipts, in England to 53, and in Scotland to 50 per cent. If the Irish expenses could be reduced to the same proportion as the Scotch, there would result a saving of £140,000 per annum.

In their recommendations Sir James Allport's Commission follow very much the recommendation of the Duke of Devonshire's Commission, that is, they report against State purchase, and in favour of amalgamation. They recommend the appointment of an Irish Commission with power to protect the public against abuse of the monopoly which would thus be left in private hands. Such a Commission should be located in Ireland, and should consist of four special members who should be leading men of business representing different districts, and one government representative. They should have power to arrange and approve amalgamations between existing companies, and also to obtain proper safeguards for the public. The government should also have the power to call upon the amalgamated companies to make such extensions as may be required.

Speaking for myself, I trust that the government will see their way to leave the railways in private hands; I consider it would be a great mistake financially in every respect for Ireland if they were purchased by the State. An amalgamated company I believe would save very much more than the £40,000 a year, which is the saving from amalgamation as estimated by the Commission; and increased facilities and cheaper fares would be an immense boon to a comparatively poor country. One splendid example of what private enterprise has done in Ireland is furnished by Guinness's brewery; and the public show their confidence by buying the shares at $3\frac{1}{4}$ times the price of issue. I doubt whether Irish railways will increase much more; it must be remembered that Ireland is a small island, and that the cost of water carriage is so very much less than of land carriage; consequently where speed is not an object it is cheaper to carry goods a longer distance by sea than by a cross-country railway. This does not apply to the transport of fish &c. where speed is of importance.

I am indebted to one of our Members, Mr. William Parker, Chief Engineer Surveyor of Lloyd's Register of Shipping, for the following particulars of cost of carriage by sea. Taking a modern cargo-carrying vessel, 275 feet length, 37 feet beam, 19 feet depth, 2,127 gross tonnage, and 780 I.H.P., the paying load carried will be 3,160 tons. Such a vessel, driven at $9\frac{1}{2}$ knots or 10·93 miles per hour, consumes 13 tons of coal per day. Taking the coal to cost £1 per ton, this shows that 100 tons of paying load can be carried one mile for 3·52 lbs. of coal costing 0·377*d.*, or less than a halfpenny for coal consumption; or for 7-8ths of a penny, including cost of working the ship and insurance. I cannot give what percentage ought to be added for dock and harbour dues and for management, and what for repairs and depreciation; but the shipowner has no land, no stations, no rails &c., to pay for and maintain. The above figures apply to a full cargo, in the newest build of ship with triple-expansion engines, over a voyage from Antwerp to Bombay and back, which necessitated an expenditure of £1,225 for Suez Canal charges.

To compare this with the cost of railway haulage, Mr. Tomlinson, one of our Vice-Presidents, has given me the following figures, taking full train-loads at a slow speed over a long distance. On a good road, with gradients about 1 in 350 varying, 40 lbs. of fair average coal per train-mile will raise steam to work at from 12 to 15 miles an hour a mineral train of 560 tons gross load, made up as follows:—

Engine	45 tons.
Tender	25 ,,
30 Wagons, each 16 tons gross load .	480 ,,
Brake Van	10 ,,
Gross load of train . .	560 tons.

The paying load will be 300 tons, or 53·57 per cent. of the gross load. The consumption will therefore be 13 lbs. of coal per mile per 100 tons of paying load. The coal used on the railway however will cost only 8*s.* per ton, against 20*s.* for that used at sea. Hence the cost of railway haulage per 100 tons of paying load will be 0·57*d.* per mile for coal.

The charges on railways are very heavy. The working cost may be assumed all round at about 50 per cent. of the receipts, and may be closely apportioned as follows:—

	Percentage of Receipts.	Pence per Train-mile.
General charges . . .	3	1·5
Way and Works . . .	8	5
Locomotive department .	13	9
Carriages and Wagons .	6	3
Traffic expenses . . .	15	10
Law and parliamentary .	0·5	3·5
Compensation . . .	1	
Rates and taxes . . .	3	
Duty	0·5	
Total Working Cost .	50 per cent.	32 pence.

Hence with trains such as that above mentioned the total working cost for hauling 100 tons of paying load would amount to about 11*d.*

per mile. But railways seldom get full train loads except when carrying coal. The increased speed necessary to work a mixed passenger and goods traffic also rapidly increases the expense of haulage. In the above comparison it will be seen that the railway speed is brought down to nearly the same as that at sea; and the low cost of working corresponds with that very low speed.

Both marine and railway haulage are cheaper than horse or traction-engine haulage. Horse haulage I suppose would cost from 8*d.* to 9*d.* per ton per mile; and Messrs. John Fowler and Co. of Leeds inform me that traction-engine haulage would average about 2½*d.* to 3*d.* per ton per mile.

It would be impossible here to give details of every industry, but as a last example the deep-sea fishery may be referred to. The estimated value of the fish taken in Irish waters amounted in 1886 to £640,000, while in Scotland it amounted to £1,397,000, and in England to upwards of £4,000,000. Unfortunately in Ireland it is a declining industry, for whereas in 1846 nearly 20,000 vessels were employed, manned by 115,000 men, now only 5,683 vessels, manned by 21,500 men, are so engaged; and what is worse, only some 4,000 of these men are wholly employed in fishing, while others are occupied only partly in fishing and partly in agriculture. The Public Works Commission report that the appliances used in Ireland for deep-sea fishing are very deficient; that in the whole of Ireland there are only 600 boats above 30 feet keel; and that many of these vessels are not decked, so that they cannot keep at sea in rough weather; also that there are no curing establishments, and that none of the nets are made in Ireland. They further state that deep-sea fishing as a national Irish industry can be profitably carried on only by the construction of harbours having sufficient depth of water for fishing craft at low tide; and they recommend the government to spend £400,000 on the construction of such low-water harbours. The Baroness Burdett Coutts is endeavouring to help the deep-sea fishing industry by lending money to buy boats and fishing gear, which the fishermen pay back by easy instalments. Under the active supervision of the Rev. Charles Davis one fishing village of over 3,000 inhabitants,

who might have been described as being chronic mendicants, are now prosperous, owing to this generous action.

The government have introduced three bills for the drainage of land within the catchment areas of the rivers Bann, Barrow, and Shannon; and they propose to make a grant of some £300,000 out of the public purse for this engineering work. The object is to prevent the flooding of the land. Whether these bills will be carried remains to be seen.

No review would be complete without a word on bank deposits. Those who wish to study the figures will find them in the annual reports presented to Parliament by Dr. Grimshaw, who gives the annual increase and decrease from 1865 to 1887, with the following results:—

			1865	1887	Increase
Joint Stock Banks		£	18,619,000	29,771,000	11,152,000
Savings Banks	Trustee	£	1,837,000	2,043,000	206,000
	Post-Office	£	207,000	2,932,000	2,725,000
	Total	£	2,044,000	4,975,000	2,931,000
Banking Capital	Subscribed	£	13,394,330	24,806,145	11,411,815
	Paid up	£	6,277,635	6,879,129	601,494

In June of the present year the amount in joint stock banks was £30,310,000, and in savings banks £5,140,000. It is pleasing to note such a large increase in the savings of the poorer classes. The increase of 11½ millions in the subscribed capital shows that the banks are going on much better now than they were in 1865.

It is difficult to say why some industries flourish and why others decline; but it is my opinion that more money should be spent on education, and more especially on technical education. Already great progress has been made, as the following figures will show. The total number of persons in Ireland above the age of five years who were unable to read and write

in 1841	was 53	per cent.	of the	population.
„ 1851	„ 47	„		„
„ 1861	„ 39	„		„
„ 1871	„ 33	„		„
„ 1881	„ 25	„		„

The following figures show the progress of national education with a decreasing population:—

	Pupils.	Schools.	Grant by Parliament.
1865	922,084	6,372	£325,583
1886	1,071,791	8,024	£851,973
Increase	149,707	1,652	£526,390

In speaking of technical education I am aware that the Chief Secretary for Ireland said in the House of Commons on 2nd July that "Ireland is in this matter far ahead of England. There has been spent on industrial schools in Ireland two-and-a-half times as much as in England, having regard to the population. In the ten years 1877 to 1887 the expenditure out of imperial sources for industrial schools in Ireland was no less than £800,000. There is besides a system of agricultural education, which is far in advance of anything of the kind in England. Since 1837 £400,000 have been spent in teaching agriculture, and the annual grant from imperial sources is for Ireland about £14,000. Having regard to these facts, I am of opinion that technical instruction, valuable as it is, is not the means by which we may look principally for promoting the material prosperity of the Irish people." But as pointed out by Mr. T. A. Dickson, M.P., it must be remembered that in order to obtain the advantage of these industrial schools a child has to be either a vagrant or a criminal, and must be sent to one of these schools by a magistrate. The statement of the Chief Secretary therefore hardly conveys a correct impression.

What I mean by technical training is teaching children to use their hands and eyes, and also giving them such practical acquaintance with the applied sciences as may bear upon the industrial employments in their district. I hope the valuable speech on the need of technical education, made by the Marquis of Hartington at our annual dinner in May (Proceedings 1888, page 170), will be widely read. I may refer to the work done in the agricultural school at Glasnevin, three miles out of Dublin, of which Mr. Thomas Carroll is the head. To this school is attached a farm of 180 acres for teaching practical farming. The Munster dairy school near Cork, started in 1880 with

a farm of 126 acres, is quite full, and frequently has to refuse pupils. The government grant to these two schools is £2,671. The Baltimore industrial school, the Public Works Commissioners state, will practically be a technical school of fishing. The Belfast technical school is very successful in training pupils in flax cultivation and spinning. Dairy schools have been established twenty years in Denmark, Sweden, Germany, and Normandy. Let me give an example of what the result has been in Denmark. A report on agricultural dairy schools has been lately presented to Parliament from a Departmental Commission presided over by Sir R. H. Paget, Bart., M.P., which states that in 1860 the British Vice-Consul at Copenhagen reported that the butter made in that country was execrably bad. What has happened? Denmark has now ten state-aided dairy schools, with the result that her exports of butter to the United Kingdom have increased as follows:—

1867 . .	80,000 cwts., value	£	422,479
1877 . .	210,322 ,,	,,	1,347,791
1887 . .	487,603 ,,	,,	2,669,123

In France theoretical and practical lessons in agriculture are now given every week in the primary schools; and a circular has been issued inviting the municipalities to provide for every district a demonstration plot of not less than half an acre for the purpose of applying the principles taught in the school.

Many manufactures are now flourishing in Ireland, owing partly to cheap labour and partly also to cheap water communication with England. The shipbuilding industry, thanks to the ability and energy of Messrs. Harland and Wolff, has made rapid strides in Belfast. In 1858 their works employed only 100 hands; they now employ 5,000, and they are building two steel ships of 10,500 tons burden. The population of Belfast has doubled in twenty-five years, from 120,777 inhabitants in 1861 to 230,000 in 1886; and they are principally employed in manufactures. Let us hope for the sake of Ireland that in future the same prosperity will continue and will extend over the whole of the island.

The EARL OF ROSSE had great pleasure in proposing a vote of thanks to the President for his most interesting Address. His review of the position of Ireland, and the contrast between this and other parts of the kingdom, were exceedingly instructive. Allusion had been made to the great decline of population in Ireland, as compared with the increase in England. Ireland being principally an agricultural country, the circumstances were naturally very different from what they were in England. The President had also alluded to the total decay of domestic industries, which had been replaced by others that were to a greater or less extent carried on in factories. This would account very much for the contrast to which attention had been directed. But if manufacturing Ireland were compared with manufacturing England, and agricultural Ireland with agricultural England, where the ordinary agricultural conditions were not more or less interfered with by the proximity of manufacturing towns, and by numerous country residences inhabited by wealthy persons at times when their presence was not required at their places of business, the contrast would be found to be far less striking. For instance in the agricultural districts of England it would be found that the influence of the railways was much more felt than was the case in the agricultural districts of Ireland. If statistics could only be got for comparing the two countries in this detailed way, a more practical conclusion would probably be arrived at than could be reached at present.

The Rev. Dr. HAUGHTON had much pleasure in seconding Earl Rosse's proposal of a vote of thanks to the President for his Address. It was not customary to criticise the address, and he would therefore content himself with praising it. There was a peculiar fitness in the Institution of Mechanical Engineers holding its second meeting in Dublin within the walls of Trinity College. The first collegiate body in the kingdom to recognise the position of engineering was King's College, London; and under the able guidance of the late distinguished Canon Moseley that school rose to a high position.

(The Rev. Dr. Haughton.)

The late professor of Engineering in Dublin, Dr. Samuel Downing, who laid the foundation and completed the structure of the Engineering School of Trinity College, was a pupil of King's College School in London; and Trinity College enjoyed the good fortune of having had as provosts two very remarkable men, namely Dr. Bartholomew Lloyd and his son Dr. Humphrey Lloyd. The great impulse given to education in Trinity College in the present century was due to Dr. Bartholomew Lloyd; and it had been brought to the high position which it now occupied among educational institutions by the skill of his better known and perhaps more gifted son Dr. Humphrey Lloyd, who from the beginning saw the importance of laying a foundation for an Engineering School in Ireland. Trinity College might also be regarded as in some sense a manufacturing body, which claimed to turn out much more important articles and to be more successful than any of the most celebrated manufacturing establishments in Dublin. It professed to turn out learned doctors, who taught their flocks what Swift so wittily described as "the incomparable thirty-nine articles." It turned out soldiers who never shrank before their foes. Near the Examination Hall in which the present meeting was assembled, there was a manufactory with a large chimney in the centre of it, always smoking, whence were turned out year by year scores of physicians and surgeons, who took their places in the army and in the colonies, and won the high esteem of their rivals wherever they met them, in Canada, in Australia, or in India. Trinity College therefore claimed to be a manufacturing establishment, and the materials turned out were of at least as high an order as expansion engines or barrels of porter. Accordingly, in the absence of the Provost, who had desired him to represent him on this occasion and to express his regret that he was not able to be present, he conveyed to the Institution a hearty welcome within the walls of Trinity College; and as himself one of a high-class firm of manufacturers he cordially concurred in offering them on the part of Trinity College a hearty welcome and in wishing them a successful meeting. The sun which had been sulking for the last week was shining out brightly this morning; and thus the only thing that might be wanting

for the complete enjoyment of their meeting—fine weather—would he hoped be continued during their stay both in Dublin and in Belfast.

The vote of thanks to the President for his Address was passed with acclamation.

The President was very much obliged to the Members for the hearty response they had given to the vote proposed by Lord Rosse and seconded by Dr. Haughton. He was only sorry the latter had not criticised the address, because he should have liked to be put right wherever he might be wrong. All he could say was that he had honestly endeavoured to present the facts as far as he could succeed in ascertaining them. The great difficulty was to get facts about Ireland; and the only thing to be done was, after having arrived at what was believed to be a fact, to lay it before the public and allow the public to criticise it. As the address had not been criticised now, he hoped perhaps the press might criticise it. He thanked the meeting most heartily for the vote of thanks they had passed.

DESCRIPTION OF A BALANCED OR AUTOMATIC SLUICE FOR WEIRS.

BY THE RIGHT HONOURABLE THE EARL OF ROSSE, F.R.S.

Among the various forms of Sluice which have been devised for use in regulating weirs on rivers, that which is described in the present paper would appear to have some advantages as regards simplicity, ease of working, and freedom from derangement.

As shown in Figs. 1 to 4, Plates 43 and 44, the sluice consists of a flap or door D, hinged on a horizontal axis A along its upper edge, or rather a little above it. From its lower edge extends outwards a cylindrical sheeting C, having for its centre the axis of rotation A, and forming a casing upon the back of the flap. The ends are closed in by flat plates at right angles to the axis; and the top of the tank thus formed may be left open. At one end and near the bottom of the door D is placed an inlet flap-valve I, and at the other end and near the bottom of the quadrantal casing C an outlet flap-valve O; both open inwards, and the two are so connected by a horizontal lever L that when either is shut the other is open. Thus when the inlet valve I is open, the tank fills with water to the level of the water-line above the weir, as shown in the transverse section, Fig. 3. The pressure, now on the curved face, is at all points radial; and the sluice is kept closed by its more or less unbalanced weight. In the other position of the lever L, when the inlet valve I is shut and the outlet valve O is open, the casing empties itself of water, and the sluice becomes an ordinary flap-valve, which opens under the pressure of the water against its front face, as shown in Fig. 4.

The sluice is thus opened or closed at will by means only of the small force required to work the valves, which need not be of larger area than required by the time that it is decided to allow for the

opening or closing of the sluice. The hinges or axes, being above the water, are out of reach of foreign bodies carried down by the current; and should a stick or log catch under a sluice and keep it from closing, the sluice can be lifted easily and the obstacle cleared away.

Two such sluices, which close openings six feet wide and three feet deep, have now been in use for several years in a weir near Parsonstown, and have worked satisfactorily; and there seems no reason why they should not do equally well on a larger scale. In that case the use of windlasses or cranes or turbines for opening and closing sluices would be superseded, with a consequent saving in labour and attendance.

The cylindrical form of the casing C need not be strictly adhered to; and in these Parsonstown sluices, which are constructed of wood, a polygonal form was adopted as more convenient to make. The valves themselves are not automatic, but might easily be made so. The weight of the sluice itself when empty may with advantage be partly balanced by a counterweight W, as shown dotted in Fig. 3, Plate 44, so as to prevent the outflow of water through the weir from being impeded or throttled by having to support the weight of the sluice when open; and also to facilitate its being lifted for cleaning. In order to prevent any risk of the sluice ever becoming blocked open by an obstruction getting jammed in between its ends and the piers, it might be preferable to place the sluice on the extreme outside face of the weir, instead of in its usual position at the inner face; it would then work quite clear of the weir in opening and closing. Whether the top of the sluice be covered or not, it is desirable that means be taken to secure that the water shall not pour over it in the event of the attendant omitting to raise the sluice in proper time after rain, as it can scarcely then be opened if the water be flowing over it; with this object the front plate D is shown in the drawings as carried up to the axis A of the sluice.

Another sluice was erected at Parsonstown with quadrantal casing C only, there being neither front plate D nor valves. It was

carefully counterpoised, and could be opened and closed by hand. The equilibrium however did not enable it to be worked quite so easily as theory would indicate, because a flange was unfortunately made to project inwards at the bottom edge of the casing at X, Fig. 4, Plate 44, against which the outflowing water impinged with some force.

Discussion.

The President said the practical way in which this automatic sluice had been worked out by the author, and its great simplicity, commended it as a good piece of engineering work, which would prove a benefit to many of those who were concerned in the regulation of weirs on rivers.

Mr. W. G. Strype considered the paper just read had particular pertinence at the present time, in consequence of the great work which had been referred to in the President's address as now in contemplation, namely that of regulating the three rivers — the Barrow, the Bann, and the Shannon—for which legislation was proposed with a view to effect the drainage of the districts they ran through. A good sluice to take the place of fixed weirs, which had been so obstructive in connection with the drainage of those and other districts, could not fail to be of great importance. The delay hinted at by the President would come as rather a disappointment, he feared, to the districts which these drainage schemes were intended to affect. All interested in those districts he believed were extremely anxious that the projects for which such substantial assistance on the part of the State was contemplated should be carried out. There was one feature however in connection with the delay that might be of advantage. Without entering now upon any criticism of these schemes, which had been prepared by eminent

engineers, he shared the opinion held by others that there were many points in which the schemes as at present proposed could be improved, and made more suitable for the requirements of the districts; and the lapse of time which would no doubt intervene would permit of those improvements and of further investigations being carried out. The arrangement of sluice devised by Lord Rosse had not been applied, so far as he understood, to rivers of any large section, and there appeared to him to be some difficulties in its application in such cases. An arrangement of sluice gates devised by an Irish engineer in London, Mr. F. G. M. Stoney, had been attended with considerable success in two particular instances in Ireland where it had already been introduced, namely at Belleck to assist in the drainage of Lough Erne, and at Ballinasloe in connection with the drainage by the river Suck flowing into the Shannon. The arrangement of Mr. Stoney's sluice was highly ingenious, and its most remarkable features were its freedom of action, its non-liability to get out of order, and the small friction attending its working, which permitted of its being rendered thoroughly and readily automatic by a simple device. In a letter which he had just received from Mr. Stoney, who was unfortunately not able to attend this meeting, his views about the particular plan devised by Lord Rosse were expressed to the following effect:—"Lord Rosse's plan is similar to schemes devised many years ago, and to several tried by the French with little or no success. All have been found decidedly defective, in so far as they will not stand heavy pressures or high velocities of current; and they all fail utterly at a critical moment, because they can be worked only so long as the water does not rise above them; let them once get submerged, and they will not open, but will remain closed just at the time when they ought to be opened. I thought I had made a hit some years ago when I designed such an appliance; but I soon learned that the French engineers had anticipated me, and had not achieved any particular success. Apart from these facts, there is in my mind a decided objection to such appliances, inasmuch as they are based on an incomplete apprehension of what is required: they aim at being movable weir caps, and do not form the weir itself, nor any portion

(Mr. W. G. Strype.)
of the weir, the whole of which is a fixture. My plan essentially is to have a sluice opening from the bottom of the river, and to give all possible discharge and free scour by rendering the channel of the river entirely unobstructed in times of floods. The sluices at Belleek and Ballinasloe do this; they represent the entire river from the bottom upwards, and they do not require any appreciable power to work them. There are no secondary valves, and what is most important they are as easily worked when submerged as when not submerged; they are under absolute control at all times, and can be perfectly relied on. You saw the sluices at Ballinasloe; a little girl has worked them under the full head, and lifted one of them at the rate of three inches for every turn of the handwheel." He had seen them himself, and it was remarkable with what ease they ran. The main feature in their construction was that they consisted of a large gate sliding vertically, and pressed against live roller frames by the pressure of the upland water. The gates and the live roller frames were balanced; and there was no appreciable friction against the face at either edge, or what would be the bearing face of an ordinary sliding sluice. To prevent leakage at these edges an ingenious device had been contrived, which, while it prevented escape of the water, was in a manner flexible and did not cause frictional resistance: near to the sides the gate itself and the jamb were shaped to half a right-angle, immediate contact being avoided; thus a V shaped form was obtained, against which a long round bar about two inches diameter was suspended and caused to touch lightly by the pressure of the water, whereby practically any leakage along the sides was prevented. With regard to Lord Rosse's sluice, he was not prepared to go quite as far as Mr. Stoney did in his remarks, because for small rivers he thought such an arrangement would be exceedingly useful; and it presented the great advantage that it was composed of very few parts, and could be constructed by workmen in the country who did not possess much skill.

Mr. Daniel Adamson, Vice-President, regarded an automatic sluice as indispensable for the satisfactory and practical working of

rivers that were also used for inland navigation. During the progress of the plans for the Manchester Ship Canal, Mr. Stoney's sluice had been brought before him as the best adapted to meet the requirements of a river like the Irwell, which was subject to great floods, while the traffic was required to be maintained alongside its course in a canal large enough for Atlantic steamers. But if that sluice, however perfect in other respects, did not act automatically, it would not meet the requirements of such a river under the circumstances of a heavy flood, so as to regulate the water-level automatically during the night when such a flood might rise. Therefore some arrangement that was entirely self-acting was in his opinion necessary in order to meet the practical requirements of a case of that sort. Even if it required only the strength of one little girl to lift the sluice, as mentioned by Mr. Strype, yet, if the girl was not present at the right moment, then the flood requirements would not be met, and calamity would follow. Especially on a river like the Irwell flowing through a large extent of low-lying land, where there was only about two feet between the ordinary height of water and the flood level which would overflow the entire district, it was absolutely indispensable to have a wholly automatic action. On the Manchester Ship Canal, where in each division the water would be admitted by three separate locks of large dimensions, the overflow by their side must be conducted on principles somewhat like those set forth in the paper for meeting the requirements of such a case. A sluice of the kind constructed by Lord Rosse for a small overflow could be adapted for a larger without any great amount of difficulty. There was indeed a difficulty in opening this sluice at high water when the flood was flowing over it. The means adopted on the Irwell to keep Salford clear from flood water consisted simply in placing in the weir a hinged flap, the hinge being situated at about half the depth of the bottom of the flap below the ordinary level of the water flowing over the weir, while the top of the flap was carried up several inches above that level: so that, when the flood water rose, its force acting upon the larger area of the upper portion opened the entire flap, and let off the flood, and so kept the river down to its ordinary level and prevented it from flooding the district. The

(Mr. Daniel Adamson.)

sluices described in the paper could easily be provided with such an overflow hinge if it was requisite, so that they might be opened automatically under the disagreeable conditions of a heavy flood. The subject he hoped would receive the consideration of all engineers who were interested in inland navigation, in order that the full benefit might be realised of the very low cost of carriage by water, to which attention had been drawn by the President in his address. What Ireland must look to for improving her position was a universal outlet all round the country for her produce, however low its value might be, so that it might be sent at the lowest possible rate to great consuming centres like Manchester, where everything which Ireland could produce was wanted if it could only be sent cheap enough. Out of the 12,000 tons of eggs per annum imported into Manchester, he was aware that 6,000 tons came from Ireland; but there was no reason why Ireland should not send there 2,000 or 3,000 tons more, and receive the money for them, rather than let it go to Denmark or Italy or elsewhere on the Continent, whence eggs were now sent into London to the extent of even 100 tons a day. Anything to facilitate economical water carriage must be a great advantage to Ireland; and he trusted that all matters connected with such a subject would receive the consideration not only of every Member of the Institution, but of everyone who wished well to Ireland and desired to improve her markets and commerce.

Mr. EDWARD B. MARTEN, Member of Council, being engaged in the control of rivers in the midland counties of England, which had to be carried on embankments where the ground had been sunk by mining, had experienced the difficulty that during the time when there was no rain the riparian owners raised the level of the water to an extreme extent by stopping outlets, putting planks on weirs, and making stanks or dams in the streams, so that the fall of only a single inch of rain caused the banks to be overflowed and their lands to be flooded immediately; and the water was then apt to get into the mines and cause great damage. The apparatus on the rivers was of the ordinary kind, and was so difficult and so slow of action that floods ensued. When he read the description of Lord Rosse's

sluice, it seemed to offer exactly the advantages that he himself wanted, in being easy to move and very effective, and capable also as he gathered from the paper of being easily rendered automatic. He thought very well of it, but found that it would not exactly suit the requirements of such rivers as he had to deal with, unless it was made wholly self-acting. It had been mentioned that such a sluice, if it could be drowned by a flood, was worse than the ordinary flap; and it appeared to him that it would be difficult to counteract this contingency. An explanation of the mode in which the sluice could be made automatic would be useful to those who felt inclined, as he himself did, to avail themselves of such a contrivance.

Mr. Arthur Paget, Vice-President, was of opinion that the friction of a flap valve turning upon a horizontal shaft above the water must be less than the friction of the same valve sliding upon a surface or running upon live rollers under the water; and he failed to see how Mr. Stoney's valve, which had been referred to by Mr. Strype, could possess any advantages over the sluice described in the present paper. There seemed to him to be no doubt that, if the main object of a sluice valve was to have as little friction as possible, the sluice hinged upon a horizontal shaft above the water and easily kept clean and lubricated must work with as little friction as any sluice that could be constructed. As to rendering it automatic, it would surely be very easy to make the inlet and outlet valves automatic in several ways. He also concurred in Mr. Adamson's opinion that it would not be a matter of any great difficulty to construct these sluices of any sizes, suitable even for the largest river for which they were likely to be required.

Mr. John P. Griffith was sure all would agree that Lord Rosse's sluice was singularly efficient for the class of work for which it was designed. It was not brought forwards by the author as applicable for large navigations; but for the special purpose for which it was designed it was highly suitable, namely for regulating the small rivers with which Ireland was so greatly infested. He used the

(Mr. John P. Griffith.)

word "infested," because these small rivers were generally a great nuisance, flooding the country; and they were often kept up by fixed weirs for the benefit of the millers, to the detriment of the district at large. Such rivers he thought could be dealt with efficiently by means of Lord Rosse's sluice. Mr. Frank Stoney's sluice, referred to by Mr. Strype, was also well known. It did not indeed get rid of friction, but the friction was greatly reduced. The large sluices which had been erected at Lough Erne were in every-day work, and there could be no doubt that they were efficient. As mentioned by Mr. Adamson, Mr. Stoney's sluices had been brought forwards in connection with the Manchester Ship Canal as an efficient means of lowering the water level, and of doing this readily with small motive power. They could practically be made automatic by turbines so arranged as to be started when the water rose above a definite level. As far as he could see there was no difficulty in making Lord Rosse's sluice automatic in a variety of ways; and he considered they should be very much obliged to the author for bringing forward this interesting subject.

The Earl of Rosse had felt doubtful whether he was proposing anything new in the sluice now described, because the idea seemed so simple; but having seen several examples of sluices for the relief of floods, as substitutes for fixed weirs, he thought none of them seemed to answer all the requirements. Having had occasion himself to put sluices in a weir where he was afraid of injury being done to property above in the event of large floods, he had devised this form of sluice. He had seen the sluices in the Irwell at Manchester, close to where the exhibition was held last year, which he supposed were those referred to by Mr. Adamson; and it struck him when he saw them that, as the whole was submerged under water black with coal, it was impossible to see what was going on, and if any obstruction got caught in the sluice it would be difficult to get it out again. So far as he understood them, those sluices were on the principle of a throttle-valve, having a horizontal axis somewhere below the water; at any rate he could not see it. His idea in designing the sluice described in the paper was that the axis should

be above the water line; he considered it ought always to be kept above the water. In another plan, proposed by Mr. Bateman for the Shannon, the sluices were to be worked by turbines; but that would be a complicated and expensive way of regulating the river. At present the sluices there put in were as simple as possible, being simple sliding sluices; there was a travelling crane which a man moved along an overhead railway for raising each sluice, and the sluice was hooked up to give the desired extent of opening. Mr. Stoney's plan he believed was intended for much larger works than his own, such as those referred to by Mr. Strype.

With regard to the adaptation of his own sluice to a long weir, such as that on the Shannon at Meelick, he presumed it would be necessary to have a foot-board along the whole length of the weir, and along the top of the sluice, as shown in Fig. 5, Plate 45; this however need not make the sluice much higher, and he considered that four or five feet would be quite ample for the height of each sluice, including the foot-board above. The space beneath the foot-board should be closed by a vertical board reaching down to the hinge, so as to prevent the water from flowing over the top of the sluice; because on one or two occasions it had happened that the water got over the sluices, and there had then been some trouble to keep them open.

For the purpose of rendering the sluice automatic and of avoiding floods, his proposal was to add a weight on one end of the valve-lever, heavy enough to open the outlet valve and close the inlet, and to the same end of the lever to attach a heavier float F, Fig. 5, Plate 45, suspended by a chain passing over pulleys P: so that, as soon as the float was lifted by the rising flood, the outlet valve would be opened and the inlet valve closed by the weight on the valve-lever, thereby letting the sluice open as the casing emptied itself of water. This would enable a sudden flood to open the sluice automatically. When the flood went down, the sluice might be closed by the attendant reversing the valves, automatic action being less necessary in this case; the proposed arrangement however would also close it automatically. Of course the important thing was to get the sluice open before damage was

(The Earl of Rosse.)

done by the flood; the closing afterwards was a matter of less importance. When the miller came after the flood and wanted to work the mill, the first thing he would do would be to put down the sluice in order to get the level of the water up.

The PRESIDENT was sure the Members would join with himself in passing a hearty vote of thanks to Lord Rosse for bringing this construction of sluice before the Institution. From his own experience on a stream with the old-fashioned sluices, the lifting of the sluices by levers and screws in the case of flood was attended with a great deal of difficulty. The plan now described he considered could be easily arranged for automatic action, as pointed out by the author, so as to prevent the flood from rising too high.

ON THE LATEST IMPROVEMENTS IN THE CLOCK-DRIVING APPARATUS OF ASTRONOMICAL TELESCOPES.

By Sir HOWARD GRUBB, F.R.S.

Equatorial Clock.—In considering the essentials of a good Clock for an Equatorial Telescope, it is necessary to note that, unlike any mere time-keeping arrangement, its motion must be continuous, not intermittent; and that it has a considerable duty to perform in driving the instrument, in addition to driving its own train and keeping a correct rate. So long as the work to which the telescope is devoted consists entirely of visual observations, it is sufficient if the clock keeps a fair rate for some minutes at a time. The most severe test applied under such circumstances is that of micrometrical observations, where a pair of spider lines have to be placed precisely over a pair of stars simultaneously. If the clock keeps its rate perfectly for the few minutes required for this operation, it suffices. Since however the spectroscope has been used in connection with the telescope, and more particularly since photography has played such an important part in astronomical work, the essentials of an equatorial clock are not only of a much higher order, but even of a different character, as will be afterwards shown.

Usual Contrivances for obtaining Uniform Motion.—These are very numerous, but in almost every case the principle is the same, namely:—the mechanical energy of the clock, whether it be that of a falling weight or water power or electricity, is used up in three ways:—

1. In overcoming the friction of the clock train &c.
2. In driving the instrument.
3. In overcoming some resistance which is so arranged as to increase very rapidly with a very slight increase of speed.

By making No. 3 very large with respect to No. 2—or in other words, by putting a large excess of mechanical energy into the machine in proportion to the amount of actual useful work it has to accomplish—it is possible to construct a clock which will have a very uniform rate for short intervals. As the total amount of mechanical energy is used up in these three directions only, it is evident that, if No. 1, or No. 2, or both, increase even in a very slight degree, the speed is reduced in accordance; but the moment it is reduced, No. 3 is largely reduced, and thus a balance is again effected and the rate brought back to the normal. It would exceed the limits of the present paper if it were attempted to describe in detail a tenth part of the many contrivances used for this purpose; and full descriptions of all the most important have from time to time been published.

The most favourite form of equatorial clock is that in which a set of governor balls propelled at a high speed rub more or less heavily against a trued ring, when they rise by virtue of the centrifugal force as the speed increases, as shown at GG in Fig. 2, Plate 46. This forms an excellent driving apparatus, and will, if properly constructed, drive a telescope of suitable size without the error of *rate* exceeding at any time 1–500th or 1–600th of the normal. The error of *position* may of course be cumulative, and increase after some time to a considerable amount. But although, as already mentioned, this amount of uniformity suffices for ordinary visual work, it is not sufficient for photographic purposes; for not only is the correction in these clocks insufficiently delicate, but the character of the correction is not what is required for this particular work.

The tendency of all these uniform-motion clocks is to bring the *rate* of the clock back to the normal, when from any cause it has been temporarily disturbed. To show that this, even if perfectly effected, is not all that is required, suppose a telescope to be pointed to any part of the heavens, the clock set going, and a photographic plate placed in the focus. Suppose the rate to be absolutely correct for the first half hour, and that then from any cause a slight increase occurs in the force necessary to turn the instrument. Almost immediately the rate diminishes, and the centrifugal force with it;

and although consequently the rate again becomes normal, yet in the meantime a slight error in *position* of the instrument takes place, say no more than is equivalent to the distance through which the instrument should have moved during one-tenth of a second. Thus even if the rate remain perfect during the next half hour's exposure, the position of the star image on the plate during the second half hour will be different from that in the first, and consequently a double image will be the result. For such work it is evidently necessary to have some arrangement by which not only shall the rate be corrected, but also any error that has crept in shall be erased. For the above reasons any successful photographs that have been taken with equatorials supplied with ordinary uniform-motion clocks owe their excellence not to the accuracy of the clock-driving, but wholly to the care and patience of the operator, who, while watching any star which he has got in the field of a second telescope carried by the photographing telescope, succeeds by means of the slow-motion handles in keeping the image of the star on the cross wires of his micrometer, and therefore steady on the photographic plate.

Connecting a Pendulum with a Uniform-Motion Clock.—Seeing that a clock with pendulum escapement can be made to go with sufficient accuracy, while a uniform-motion clock cannot, it is not to be wondered at that attempts have been made from time to time to connect one with the other mechanically. But a pendulum is so very sensitive to any slight variation in driving power that the result has always been a failure: in fact it has been found that the uniform-motion clock invariably controlled the pendulum, instead of the pendulum controlling the uniform-motion clock. By means of electricity however it is possible to control a uniform-motion clock from a pendulum clock, without re-acting on the pendulum in any detrimental manner. So far as the author is aware there are only four forms of electrical control.

First form of Electrical Control.—The first form of electrical control is Dr. Gill's, as applied to the 15-inch equatorial at Dun

Echt with admirable success. In this an electric current is sent once a second from an independent pendulum, which may be any distance away. The current passes through a certain wheel in the clock, with contacts so arranged that, if the clock is going exactly with the pendulum, the current is sent in a direction which keeps one of two rubbers rubbing on a quick-moving wheel of the clock. If however the clock goes the least too fast, the wheel has revolved a little farther than it should at the moment the next current comes from the pendulum, and the current is sent in such a direction as to cause both rubbers to rub on the wheel. If on the contrary the clock has gone a shade too slow, the current is sent in a third direction, which lifts both rubbers off. This control, so far as it goes, acts almost perfectly; but it is open to the objection that, as it corrects the errors of only the particular shaft to which the contact wheel is attached, any errors in wheels between that and the telescope screw are unaffected by it. Also the author finds in practice that, when it is attempted to control a clock by alteration of friction on any heavy quick-moving part, the alteration takes some little time to act, and then generally overdoes the correction, causing what is termed "hunting."

Second form of Electrical Control.—The second form of electrical control is the first introduced by the author, and is shown about one-quarter full size in Figs. 3 and 4, Plate 47. Fig. 3 is a plan, and Fig. 4 an elevation of the arrangement, which is attached to the back of the main clockwork at E in Fig. 1, Plate 46, where it is represented to a smaller scale of only one-eighth full size. A is a portion of one of the spindles of the uniform-motion clock, or of any shaft coupled thereto: R R R are the three wheels of an ordinary mitre *remontoire* train driving by the weight W the scape-wheel C, into the teeth of which gear the pallets T T driven by the electric pendulum P. The electric pendulum is connected with any independent clock, and driven by a current from it. To the weight-carrying arm of the *remontoire* is attached a chain or wire, which communicates any motion it may receive to the overhead lever L; and from the other end of the lever hangs a smaller weight F, which

is therefore raised when the *remontoire* arm is lowered, and lowered when the arm is raised. D is a disc of metal on a vertical spindle of a uniform-motion clock, and revolves rapidly, say 300 revs. per minute. When the small weight F is below its mean position, it is in contact with the disc D, and its lower end being coated with leather produces a considerable amount of friction, and therefore tends to retard the speed of the clock; when the weight is above its mean position, it is altogether out of contact with the disc D. The action is as follows:—supposing the shaft A to be revolving exactly one per minute, the pendulum to be vibrating exactly 60 per minute, and that there are 30 teeth in the scape-wheel, it is evident that the *remontoire* arm, and therefore the two weights W and F, will vibrate up and down through the same distance each second, and that the mean position of all will be the same each second. Under these circumstances, the small weight F will be alternately half a second in contact with the disc D, and half a second out of contact; and the uniform-motion clock is itself rated just so much fast, that the resting of the small weight on the disc for half a second in each second will bring the rate right.

Now supposing an error of acceleration to arise in the uniform-motion clock, the mean position of the *remontoire* arm will rise; therefore the small weight F will fall, and, instead of rubbing in contact with the disc D for 0·5 second, it will rub for 0·6 or 0·7 second, according to the extent of the error. This will tend to check the rate, and this check will continue till the relative position of the uniform-motion shaft A comes back to what it was when the clock was going correctly. If a retardation occurs, the reverse effect will take place, and the small weight will rub on the disc for only 0·4 or 0·3 second, instead of 0·5, until the error is corrected. So far as described, there was no particular novelty, as most of this arrangement had in principle been tried before. The failure that had resulted had been due to the fact that it was found impossible to prevent the pendulum from being influenced by the difference of force on the pallets under varying circumstances: the reason being that the pendulum had been driven by the scapement, and not by electricity as in this case.

This difficulty was got rid of, firstly, by making the pallets, now that they are not required to drive the pendulum, of such form that the teeth of the scape-wheel impinge upon them nearly at the angle of repose; and secondly, by driving the pendulum by an electric current from another clock, thus virtually rendering the pendulum not a pendulum at all, but a lever worked backwards and forwards by electricity, and not subject to alteration in its rate by slightly varying force on the pallets. This arrangement is somewhat similar to Dr. Gill's. It is simpler for attaching to any existing clock, but not so delicate as his; and is open to the same objections. It is capable however of very good work, as may be judged from the chronograph sheet of the Dunsink Observatory chronograph.

Third form of Electrical Control.—The third form of electrical control is that devised by the author for Mr. Isaac Roberts. It has proved so successful with him at Liverpool, and with Professor Pritchard, who has had it recently attached to the Oxford equatorial, that photographs have been exposed for fifteen minutes with the telescope to which it has been attached, and have yielded perfect images of stars without any hand and eye guiding. The arrangement consists, firstly, of a *remontoire* train driving a good mercurial or other compensated pendulum, the driving of the train being of course entirely independent of the equatorial clock giving motion to the telescope; secondly, of a detector apparatus, which detects any difference between the rate of this standard pendulum and of the equatorial clock; and thirdly, of a correcting apparatus, which corrects automatically any error discovered by the detector.

The corrector itself consists of two parts—an "accelerator" and a "retarder;" and these will first be described. In Fig. 8, Plate 48, drawn about one-quarter full size, S^1 S^2 S^3 is one of the shafts, between the driving train of the equatorial clock and the worm W which drives the right-ascension sector; and this shaft is cut into the three parts denoted by the distinctive letters. At one end the first portion S^1 of the shaft carries a wheel 1, immediately adjoining which is a second wheel 2 mounted on the intermediate

portion S^2 of the shaft. At the other end of this intermediate portion of the shaft is fixed a third wheel 3, which immediately adjoins a fourth wheel 4 fixed on the third portion S^3 of the shaft. On the first and third portions of the shaft, S^1 and S^3, are also mounted loose the brass discs D^1 and D^3, which adjoin the two pairs of wheels 1–2 and 3–4. Each of these brass discs is furnished with a stud, on which a small pinion is mounted; the pinion P^1 belonging to the disc D^1 gears across the pair of wheels 1–2; while the pinion P^3 belonging to disc D^3 gears across the pair of wheels 3–4. Under normal conditions, if no error exists in the equatorial-clock rate, the arrangement of wheels and pinions just described revolves as one piece, the three portions of the shaft rotating at the same speed. But it is possible, by an arrangement which will presently be explained, to stop the rotation of either of the discs D^1 and D^3; and as soon as this occurs the pinion of the stopped disc has to act as a transmitter of motion from one to the other of the two wheels into which it gears. If the two wheels of each pair had the same number of teeth, the speed of both wheels would still remain the same; but in reality the number of teeth in the two wheels of each pair is different; and hence the stopping of either of the discs causes a variation in the rate of rotation of the two adjoining wheels relatively to each other. For instance, in the case of the first pair of wheels 1–2, let wheel 1 have 30 teeth and wheel 2 have 29, and suppose that the shaft S^1 is rotating once every 60 seconds. Then, if the disc D^1 be stopped, the wheel 2 will be made to revolve in 29–30ths of the time occupied by the wheel 1; or, in other words, the rate of the intermediate portion S^2 of the shaft will be accelerated to one revolution in 58 seconds. In the same way, by reversing the positions of the wheels in the other pair 3–4, the stoppage of the other disc D^3 can be made to effect a retardation of the third portion S^3 of the shaft relatively to the intermediate portion S^2. The edges of the two discs D^1 and D^3 are cut into very fine teeth, as shown in Fig. 9; and the stoppage of the discs when desired is effected by causing a comb attached to the armature of an electro-magnet M to engage with these teeth. The whole apparatus constitutes a very convenient arrangement for accelerating or retarding the driving motion imparted to the

telescope by the equatorial clock; and that it is capable of very good work is shown by the photographs taken by Professor Pritchard and Mr. Roberts, in which the star discs are perfectly round, though exposed for fifteen to sixty minutes, and no hand guiding used.

When necessary, this apparatus is brought into action automatically by the "detector" in the following manner. In Figs. 7 and 8, Plates 47 and 48, C is a scape-wheel mounted on the 60-second spindle of the controlling clock, and driven from that spindle through a spiral spring N, Fig. 8, so that no error in the equatorial clock can affect its rate or that of the standard pendulum. On the same spindle there is also mounted behind the scape-wheel an ebonite disc E, Fig. 9, driven by the equatorial clock and carrying two insulated rings R R, Fig. 8, which are respectively connected metallically with two platinum plates A A inserted in the face of the disc E, Fig. 9. Between the scape-wheel and the ebonite disc there is also mounted loose on the spindle a lever L, carrying at one end a platinum bridge B, which is of such a length as to project between the platinum plates A A, and in its mid-position bears against a piece of rock crystal let into the ebonite disc between the two platinum plates. The other end of the lever L is formed into a fork, between the arms of which projects a pin carried by the scape-wheel C; the arms of the fork are provided with set-screws, by means of which the amount of play allowed to the pin in the fork can be adjusted. The insulated rings R R are electrically connected with the magnets M M of the accelerator and retarder already described by means of fine platinum wires J J wiping against them; and the action of the whole arrangement is as follows. The scape-wheel C, being driven by the control clock, has an intermittent movement corresponding with the beats of the pendulum, while the ebonite disc E, being driven by the equatorial clock, has a continuous movement: so that, even if the scape-wheel and disc make a whole revolution in the same time, the pin carried by the scape-wheel will be constantly oscillating between the set-screws of the fork at one end of the lever L, which is driven by friction from the ebonite disc. The set-screws are adjusted so as to allow of this oscillation taking place without interference, so long as the rates of

the equatorial and control clocks remain uniform; but if the equatorial clock either loses or gains with respect to the standard, the pin on the scape-wheel comes into contact with one of the set-screws of the lever L, and shifts the lever on its spindle, bringing the platinum bridge B into contact with one of the two platinum plates A A, and transmitting a current which brings into action the accelerator or retarder as may be required. The period during which the accelerator or retarder remains in action will depend upon the amount of the error to be corrected, and the proportions of the pairs of wheels 1–2 and 3–4. With the proportions above described, the correction introduced is one-thirtieth of the rate: so that, in order to correct an error of one-fifth of a second, the accelerator or retarder, as the case may be, would have to remain in operation $30 \div 5 = 6$ seconds. As soon as the correction has been made, the lever L will resume its normal position; and the bridge B coming then into a midway position between the two platinum plates A A, a current will cease to be transmitted, and the accelerator or retarder will be thrown out of action.

It is to be noted that this apparatus not only corrects any temporary disturbance of the equatorial-clock rate, but also cancels errors which have already occurred. This third form of control is free from the objections of the first and second. The detector part of the apparatus is close to the screw spindle W, Fig. 8, being removed from it by only one pair of wheels; and the correction is not applied in the same manner by checking the speed of the clock, but by introducing a differential gear, which acts until the error is cured, and then drops out of gear automatically.

Fourth form of Electrical Control.—The fourth and last form of electrical control to be described is considered by the author to give the best results, combining as it does the best points of the other systems. In all four forms of control the apparatus may be divided into two distinct parts: the first that which detects the error; and the second that which applies the correction. In this fourth and last form the author uses a detector similar in principle to that adopted in Dr. Gill's form; and a corrector or pair of correctors

—accelerator and retarder—similar to that in his own form last described. He adopts Dr. Gill's system of detection, because it is capable of being made conveniently on a larger scale than his own; that is, a second of time is represented by a larger linear quantity. He adopts however the system of correctors by differential wheels in preference to Dr. Gill's, for reasons that will be explained.

The detector, shown one-quarter full size at D in Fig. 10, Plate 49, and full size in Fig. 11, consists therefore of a disc built up of three plates of brass separated by two plates of ebonite, carried either on the screw-shaft W itself, or, as shown in Fig. 10, on a shaft S as close as possible to it. The edges of the brass discs are wiped by three silver springs, and are cut so as to present a series of electrical contacts in the manner shown in Fig. 11. In the central disc the contact is very short, not more than one-fortieth of a second; in each of the two others it extends over nearly half a second: in Fig. 11 the contacts are shown shaded, and the intervals between them are left blank.

The action of this apparatus is as follows. A pendulum beating seconds, shown diagrammatically at P, Fig. 10, Plate 49, closes a circuit once every second, and allows a current from the battery B to flow through the wires 1 and 2 to the general contact-ring of the detector D. If the telescope is being driven properly, this closing of the circuit by the pendulum will be synchronous with the passage of one of the central series of peripheral contact-pieces under the central contact-spring connected with the wire 3, and the current will thus follow the circuit 1, 2, 3, 4, 5, bringing into action the central electro-magnet 4 of the relay. This relay has a vibrating lever L, shown two-thirds full size in Fig. 12, Plate 50, which, when acted upon by the armature of the central electro-magnet, is held in the central position, so that no current is transmitted by the relay, and the driving of the telescope is not interfered with. Supposing however that at the instant the pendulum closes its circuit the telescope is slightly ahead of its proper position, then, instead of one of the central series of contact-pieces in the detector being under the central contact-spring when the circuit is closed, one of the left-hand series will be under the corresponding left-hand

contact-spring, Plate 49, and the current will follow the circuit 1, 2, 8, 9, 5, bringing into operation the left-hand electro-magnet 9 of the relay, and drawing the lever L to that side. The effect of this movement of the lever is to close a connection at 10, and cause a current from the relay battery G to traverse the circuit 13, 10, 11, 12, and bring into action the magnets M actuating the clamp which will hold the disc R of the retarder, thus retarding the motion of the telescope. On the other hand, if the telescope falls behind its proper rate, the current transmitted by the pendulum will traverse the right-hand circuit 1, 2, 6, 7, 5, the lever L will be drawn over by the magnet 7 to close a connection at 14, and the current from the relay battery G will traverse the circuit 13, 14, 15, 16, and bring into action the accelerating disc A.

The shaft S, Plate 49, makes one revolution in twenty seconds, so that during each revolution twenty correcting currents are transmitted by the controlling pendulum P. The proportions of the accelerator A and retarder R are also such that the alteration made in the driving of the telescope equals one-fortieth of the time during which the accelerator or retarder is put into operation. Thus, if the driving of the telescope from any cause becomes one-twentieth of a second in arrear, the controlling apparatus will correct the error by bringing the accelerator into action for a period of two seconds, and so on.

The advantages obtained by this form are, firstly, the detector being placed close to the screw-shaft detects any errors which occur, not only in the clock itself, but also in any of the gearing between the clock and the screw-shaft or counter-shaft on which the detector is mounted; whereas in Dr. Gill's form and in the author's earlier form the utmost which the control could do was to correct errors in the clock itself. Secondly, so long as the correction was applied as in Dr. Gill's and the author's earlier forms, by alteration of friction on some quick-moving spindle, there was an inducement to keep down the *vis inertiæ* of the governors; but by using the differential wheels for correctors this is no longer the case, and this particular governor, of which a vertical section is shown one-quarter full size in Fig. 14, Plate 50, has about 10,000 foot-pounds of energy per

minute, and is thus enabled to ride over small obstacles in a manner in which the ordinary light governor cannot.

The results of trials with the clock are most satisfactory. The moment an error exceeding one-fortieth of a second is introduced, it is detected by the detector, and the correctors are set to work to erase it.

The seconds pendulum, by which the control is exerted, may be a mercurial or any other kind of compensated pendulum; and its bob carries a fine point, which at each oscillation closes an electric circuit by passing through a globule of mercury, and so transmits the current to the detector gear already described. The mode of driving the pendulum is as follows. The upper part of the pendulum rod carries a light arm projecting at right angles, which as the pendulum oscillates from right to left picks up a weight resting on a supporting lever. If the lever remained in the same position, the arm would simply deposit the weight again upon it at the same level during the reverse oscillation, and the pendulum would receive no impulse. But just before the weight can be thus deposited again, the closing of the electric circuit by the pendulum brings into action an electro-magnet which depresses the supporting lever. On the current ceasing, the lever is raised again by its counterweight to its original position, thereby lifting the weight off the pendulum arm. The effect of this is that the weight remains resting on the pendulum arm during a longer arc while descending than while ascending, and hence the pendulum receives the necessary impulse.

Hand Correctors for Refraction.—Besides the ordinary slow motion in right ascension, it is found desirable to have for this photographic work a very fine motion: not for the purpose of attempting to supplement the clock, as is usually the case with uncontrolled clocks; but in order to correct for refraction, which the clock cannot be made to take under its control. For this purpose nothing could be better than a pair of correctors, similar to those worked by the automatic control, but actuated by the observer himself with a pair of contacts held in the hand. It is evident however

that the same pair of correctors as are actuated by the automatic control cannot be used for this purpose; for if these be tampered with, the automatic control will treat the effect thus introduced as an error, and will proceed to correct it at once. It is necessary therefore to have a new set of correctors, shown half full size in Fig. 13, Plate 50; and these must be in front of the detector D, as shown at H in Fig. 10, Plate 49, and not behind it as the others are. If it should seem that the apparent complication of wheels and gearing on the counter-shaft S may militate against its perfect action, it should be kept in view that in the normal state of affairs these correctors act simply as clutches, and the whole shaft revolves as one piece; and it is only when an error is to be corrected that any of the wheels require to act.

Slow Motion in Declination.—It is also necessary to have a very delicate motion in declination. There are various forms of motion for this purpose; but the only one which is absolutely free from all backlash or loss of time is the so-called German slow motion, which consists simply of a screw pushing a projecting arm attached to the telescope, the arm being kept in contact by a spring. This is much used in transit instruments &c.; but in equatorials it is very objectionable, for the spring must be made very long and pliable in order to have play enough and to be tolerably equal in strength in all parts of its journey; and the consequence is that the spring is continually giving way before the instrument, when it is pushed by the hand for quick motion; and it is also much affected by a very slight want of balance, which in an equatorial is not easily avoided.

In the arrangement shown one-third full size in Figs. 5 and 6, Plate 47, the advantage of having all backlash taken up by a spring is retained, while a very stiff spring can be employed. The screw E, by which the delicate adjustment in declination is made, has a right-hand thread working through a nut N, and has a spherical end B bearing in the cross-head H, which pushes the projecting arm attached to the telescope. Thus the turning of the screw varies the distance between the nut and the cross-head. At S is a short stiff spring, which by means of the left-handed screw G and sleeve V

exerts a pressure on the cross-head H. A square prolongation J of the screw E enters a corresponding square hole in the screw G, so that the two screws turn together. Hence every increase of distance between the nut N and the cross-head H is accompanied by an equal decrease in the distance between the cross-head H and the stiff spring S; and thus the pressure exerted by the spring remains constant, whatever may be the position of the cross-head. This contrivance answers its purpose admirably.

Discussion.

The President believed the application of photography in connection with the telescope had helped materially to advance the science of astronomy, because he understood that, if it had not been for photography, some of the stars which astronomers had been able to photograph could not have been seen at all. The difficulty with photography was to keep the telescope exactly on the star at the same rate of speed as the star. When it was found that the telescope could be kept going for sixty minutes, so as to photograph a star perfectly round, as described in the paper, it was evident that the speed of the telescope was successfully controlled to the exact speed of the star, and that the mechanism employed was of a very delicate kind. It was certainly a proof of great engineering skill on the part of Sir Howard Grubb that he had succeeded in constructing a clock-driving apparatus of so accurate a kind as to enable a telescope to do this work.

Sir Robert S. Ball, Royal Astronomer of Ireland, had listened with great interest to the description of this admirable contrivance for enabling the telescope to keep constantly pointed precisely to the same star. It must be recollected that this was not pointing

in any rough sense of the word. The problem to be solved was of a far more delicate kind. The nearest approach to a mathematical point was the intersection of two spider lines stretched across the field of view at right angles to each other; and the telescope was pointed so that the star remained exactly where the lines crossed. The star was moving, or appeared to be moving in consequence of the rotation of the earth; and what was wanted was to follow it with the heavy telescope and with a photographing apparatus, and to keep the star for an hour together exactly at this intersection of the cross lines. Nothing showed more clearly how thoroughly Sir Howard Grubb had accomplished this object than the further contrivance which he had introduced of a very fine motion to allow of making the correction for refraction. It was an extremely small motion, whereby, as the elevation of the star above the horizon altered, a minute correction was introduced which the clock was unable to effect.

Allusion had also been made in the paper to the chronographic sheets at Dunsink Observatory, where he should be most happy to receive a visit from any Members of the Institution who might be interested in such matters. They would there see, not this extremely delicate apparatus which Sir Howard Grubb had described as his latest form of electrical control, but one of the earlier apparatus, the first form introduced by him (pages 306–308), which was in itself an extremely beautiful one, and enabled observations to be recorded with a very high degree of accuracy. The observations were taken with the transit instrument, and recorded on a circle made to revolve by means of one of these compensating contrivances which the author had introduced. He regretted that he was not in a position to show a photographic apparatus with the more recent contrivance, and that he had not yet been able to order for Dunsink Observatory one of these splendid photographing telescopes, which had been made by Sir Howard Grubb for many other parts of the world. The place and the plans were ready at Dunsink, and all that was now required was the sum of £1,930 for enabling the work to be immediately begun. Unfortunately at the present time it was not so easy to obtain that amount; but if the financial difficulty could be surmounted,

(Sir Robert S. Ball.)

this beautiful apparatus would certainly be adopted at Dunsink and applied to photographing the heavens. He had great pleasure in moving a vote of thanks to Sir Howard Grubb for his very interesting paper.

Professor Ryan asked whether it would not be worth while to make an automatic correction for refraction, in so far as the amount of refraction depended on the altitude of the star. The automatic correction could indeed be supplemented by a manual adjustment, when necessary; but for short periods such adjustment he thought could be diminished in amount, if not dispensed with altogether. Reference had been made in page 314 to "refraction, which the clock cannot be made to take under its control." Although he should be reluctant to put any extra duty upon an already over-taxed clock, yet he thought it could be made to take this correction occasionally under its control, if it were worth while, so far at least as to permit of photographing a star near its greatest altitude, under constant atmospheric conditions of density and temperature. The ingenious devices described in the paper rendered it an intellectual treat, more especially in regard to the correction adopted for re-establishing the true position of the star on the photographic plate, in addition to the correction of any error in rate.

The Earl of Rosse said the contrivances described in the paper were so ingenious, and at the same time so complicated, that they would have to be gone over carefully in order to apprehend fully all the various details. He had himself worked a little at photography and at clock movement in connection with his own telescope; and had constructed a clock which seemed to go very fairly when electrically controlled, and certainly was vastly superior to what it had been before it was so controlled. His telescope being out in the open air, he was obliged to confine himself mainly to the simplest arrangements; because all elaborate mechanical contrivances, such as those described in the paper, in order to work properly must of course be well looked after, well oiled, cleaned, and kept free from

rust. With an instrument out in the open air there was a great deal of difficulty in accomplishing this: so that he had not thought it desirable to go in for any more complications than in the clock he had at present. The mechanical difficulty which had deterred him from expending any more labour on the clock was the difficulty of keeping the metallic mirror invariably in the same position. If the mirror of a reflecting telescope like his own were tilted half a degree, the reflected ray would be tilted a whole degree; and if the metallic speculum were confined by rigid clamps and screws, so as to keep it invariably in the same position, it would be pressed more or less out of shape. It must be most carefully handled, otherwise the smallest unequal strain would put it out of shape, and the accuracy of vision would be affected. Between this difficulty and the other difficulty of keeping the speculum steady on its bed, it was no easy matter to accomplish what was wanted. In his trials of photography he had succeeded in many instances in keeping a star for an hour and a quarter within about 1-16th of an inch of the proper place, but that was obviously not enough; it would not do to have the image of the star wandering through 1-16th of an inch; the image would be a blurred one, and probably with a faint star no image at all would be obtained. In all these cases he had found that the deviation of the star was not in the direction of a straight line, east and west; but it described a variable curve according to the tilt of the speculum, proving that the speculum itself was at fault. In regard to the accuracy of the clock therefore he had evidently gone as far as it was desirable to go, so long as the speculum itself could not be held steadier. The telescope of Mr. Isaac Roberts at Liverpool, constructed by Sir Howard Grubb, was a reflecting telescope; but how the difficulty of the tilt of the mirror was got over he did not know. The mirror in that telescope he believed was silver on glass, the weight of which was of course much less than that of speculum metal. For an observatory in the neighbourhood of London a mirror of considerable size was now being constructed; but the owner was not sanguine of being able ever to accomplish the mechanical problem of keeping the mirror exactly in an invariable position, and considered that nothing but hand correction throughout

(The Earl of Rosse.)
the whole exposure could do it. To correct by hand was of course most tedious; and if Sir Howard Grubb's contrivance would really effect what others thought could be done only by hand, he would have accomplished a very valuable work which would be a great boon to astronomers.

Mr. W. H. Maw considered the apparatus devised by Sir Howard Grubb was so perfect that it really left no scope for criticism. It would perhaps be interesting however if a few of the measures of time given in the paper, as defining the delicacy of the apparatus, were converted into measures of distance. The apparatus he believed had been especially designed to be used with the class of photographic telescope which had been agreed upon by the Paris congress last year as best adapted for the general photographic survey of the heavens. Those telescopes were to be refractors, with 13·1 inches aperture and about 11 feet focal length; and as they were mounted approximately at the centre of their length, it followed that the photographic plate on which the image of the stars would be imprinted would be carried at about 5½ feet radius. It was also the fact, he believed, that with such telescopes a twelfth-magnitude star would have an image of about 1-700th of an inch diameter on the plate. Consequently an exceedingly slight distortion would entirely destroy the image; and the problem Sir Howard Grubb had to face was to carry a plate at 5½ feet radius so steadily that at no time should that image of 1-700th of an inch diameter be distorted. This meant that the error in position should certainly at no time exceed one-thousandth of an inch. That was a problem which all mechanical engineers would agree was an extremely difficult one to solve; and that it had now been practically solved by the author was a matter of which he had every reason to be proud.

Mr. Henry Davey, having himself devoted some attention to synchronising mechanism, believed the contrivances described in the paper constituted the most beautiful and most perfect synchronising mechanism that had yet come under his notice. In

multiple telegraphy the synchronising was done formerly by means of tuning forks, but now by means of vibrating reeds which acted on the same principle of emitting a musical sound of distinctive pitch; and it occurred to him that the principle there involved might possibly be made use of for such purposes as those contemplated in the paper. For synchronising clocks in different rooms of his own house from one standard clock, he had been using a seconds pendulum driven by means of electricity. Electric clocks however were notoriously bad time-keepers, owing chiefly to the variation of the electric current which constituted the driving force. He had therefore constructed an electric clock in which the seconds pendulum received an impulse only once a minute, instead of once a second: by that means the pendulum could be worked from a battery, and there was accordingly very small variation in the driving force, because the battery remained practically constant. The seconds pendulum carried a little ratchet-wheel having thirty teeth, which was rotated one tooth in each double swing of the pendulum by a paul on a lever attached to the clock-case. From the face of the ratchet-wheel projected a pin, which during its rotation closed once in every minute an open contact-maker on the side of the clock-case, and allowed an electric current from the battery to lift a weight, which by its fall gave the requisite slight impulse to the pendulum in the return stroke. Thus the pendulum was driven once a minute by a constant weight, which was lifted by electricity. It was accordingly a free-swinging pendulum for fifty-nine seconds; and as it had no train of wheels to drive, it moved with very little resistance, while at the same time the increase in the length of the arc due to the slight impulse during the sixtieth second was so exceedingly small as scarcely to be detected. In this way he had been successful in getting pretty constant time-keeping from the pendulum; but not very successful yet in producing perfect synchronism in the other clocks. He fully realised therefore the difficulty and the nicety of the problem dealt with by the author; and could not but regard with the greatest admiration the synchronising mechanism whereby it had been so successfully solved.

Mr. G. Johnstone Stoney observed that the subject of photographing the stars had risen to its present importance in consequence of the vast number of stars which could be photographed beyond what could be seen by eye observations. Hence the production of such an accurate clock-motion as would allow of a prolonged exposure of the plates had become of extreme importance to the contemplated photographic survey of the heavens. Although the arrangement devised by Sir Howard Grubb had been spoken of in his paper as being apparently complicated, he thought if the actual apparatus itself was examined in detail it would be found to be much less complicated than it appeared to be. When its several portions were consecutively considered, the arrangement was really a remarkably simple one, while the perfection of its action seemed to be complete.

As regarded the question of refraction, it should be borne in mind that within a considerable distance on each side of the meridian the variation in the refraction followed such laws that the effect of refraction could be almost accurately allowed for by a very slight alteration in the speed with which the telescope was driven. It was a great pity for the advancement of astronomy that there were such serious difficulties as those referred to by Lord Rosse in the use of large reflecting telescopes. At present he did not know that there was any practicable way of getting over the defect which arose from the slight shifting of the mirror in a large reflecting telescope upon its supporting bed of levers. In a mirror having so great an extent of surface as that in Lord Rosse's large telescope, which was six feet in diameter, it must be remembered that the deviation of the spherical form from the parabolic form amounted to only 1-10,000th of an inch at the circumference, where it was greatest. It was therefore evident that the support which must be extended over the whole of the back of the mirror needed to be extremely equable. The mirror must indeed be placed in much the same state as if it were floating on mercury, in order that its mass of 4 tons weight might be equally supported at every point, without sagging down anywhere so as to destroy its optical accuracy. This result could not at present be attained, so far as he knew, if at the

same time the mirror were grasped so firmly as to prevent it from shifting slightly in its bearing upon its bed of levers, whenever the telescope was moved from one altitude to another; he did not see that there was any practical means at present of correcting the motion of the image due to this. If it were not for this difficulty, reflecting telescopes would offer an immense advantage in astronomical photography, from the circumstance that the foci of all the rays were absolutely coincident, instead of being only approximately coincident as was the case in refracting telescopes. It was by refractors however that the great photographic survey of the heavens was about to be carried out.

One matter of great importance in regard to the success attained by Sir Howard Grubb with the apparatus described in the paper was that in this arrangement the correction was applied close to the driving axis, so that there were no errors arising from the gearing —a class of errors which it had hitherto been found practically almost impossible to eliminate. To attain this result had been an extremely difficult problem; because close to the driving axis, which it must be remembered was driving the telescope at the rate of only once round in twenty-four hours, the motion was necessarily very slow, and consequently there were great practical difficulties in making the extremely delicate correction which had to be applied over a small fraction of a second; but these difficulties seemed to have been perfectly got over by the arrangement which Sir Howard Grubb had contrived. He earnestly hoped that Ireland would not be left permanently in the position described by Sir Robert Ball of not having in her own national observatory at Dunsink one of the telescopes for the photographic survey; and that the money requisite for procuring such an instrument would in some way be provided.

Mr. JEREMIAH HEAD, Past-President, said he happened to be the member of Council to whom, according to their usual practice, this paper had been referred for consideration before it was finally accepted by the Council; and he need scarcely assure the Members that his report had been that not only was it worthy of their acceptance, but that they might be extremely glad to have so

(Mr. Jeremiah Head.)
valuable a contribution to their Proceedings. Every one present, he was quite sure, would feel very modest after reading this paper; for to follow it and understand it thoroughly a man must not only be a mechanical engineer, but he ought also to know a good deal of photography, and to be more or less of a clock maker, an electrician, an optician, and an astronomer. One lesson to be learned from such a paper was that the fundamental principles of physical science were common to all its branches, and underlay every investigation and improvement on which mechanical engineers might be engaged. He desired to express his own belief that the paper was a most valuable one, and that they were all very much indebted to Sir Howard Grubb for having contributed it to this meeting. He had great pleasure in seconding the vote of thanks which had been proposed by Sir Robert Ball.

Sir Howard Grubb said it was the fact, as mentioned by the President and Mr. Stoney, that by means of telescopes a number of stars had now been photographed which were too small to be seen by the naked eye or even with the aid of a telescope.

With regard to refraction (page 318), it was not merely a question of correcting in one direction alone, that is either in declination or in right ascension; but it was requisite to correct simultaneously in both. The amount and the proportion of the two component parts which made up the resultant correction varied in the most complicated manner, according to the position of the star in the heavens at the time. In this connection he might refer to one matter, which had been slightly touched on by Mr. Stoney, but which had been designedly omitted from the paper, because it was more a matter pertaining to the working of telescopes and to the consideration of astronomers than of mechanical engineers: namely that by means of the apparatus described in the paper it was possible to correct to some extent for refraction. For near the meridian, which was always chosen as the position for photographing a star, the effect of refraction was nearly constant through a considerable distance on each side; and whether the star was east or west of the meridian the refraction had always the effect of

making it appear to move a little slower than it really did. So far as concerned the regulating clock, any ordinarily good time-piece would answer. The reason he had himself adopted a special pendulum was not because it was any better than a good time-piece, but in order that it might be possible for the astronomer to give the pendulum a slight losing rate so as to correspond with the effect of the refraction. The amount of losing depended on the position of the star in the heavens. In that way it was possible to correct the refraction very nearly, for a considerable distance on both sides of the meridian.

In the reflecting telescope used by Mr. Roberts at Liverpool, to which Lord Rosse had referred (page 319), there were undoubtedly those additional difficulties to deal with which were always encountered in a reflector, beyond the difficulties that attended a refractor. He hardly knew indeed how Mr. Roberts had succeeded in getting such good results as he had obtained; but one point which he might mention was that in constructing that telescope special provision had been made to guard against one of the two distinct motions to which the mirror was liable, namely the bodily shifting of the mirror itself on its supports. Of the effect of this motion he had got rid to a certain extent by curving the back of the mirror to a similar curve to its face, making the mirror convex at the back, instead of flat; the effect of any movement on its bed was thereby much reduced, the reflected rays being still directed to the same focus.

He was sorry that Mr. Davey had not gone a little further into the matter of synchronising clocks (page 321), about which he himself knew but little, and should have been glad to hear more.

In the contrivances described in the paper it must not be considered that refinement had been carried beyond what it was worth. He did not profess to eliminate errors smaller than something like 1-40th of a second; but one of the astronomical photographers corresponding with him had strongly urged him to go as far as 1-100th of a second. At present however he could not see his way to go further than 1–40th, which he believed was really ample for all such purposes. As the apparatus itself was too

(Sir Howard Grubb.)
inconvenient to bring for inspection at the meeting, he trusted that any of the Members who were interested in the matter would come and see it at his works, where he should be most happy to show them the whole construction.

The President was sure all the Members would heartily concur in the vote of thanks to Sir Howard Grubb, which had been proposed by the Royal Astronomer and seconded by Mr. Head.

DESCRIPTION OF TRAMWAYS AND ROLLING STOCK AT GUINNESS'S BREWERY.

By Mr. SAMUEL GEOGHEGAN, Engineer to the Brewery.

In many of the large manufactories of the present time the amount of internal traffic soon reaches a point at which horse or manual haulage becomes both inconvenient and expensive, and presents a very serious obstacle to further profitable extension. This is more particularly the case where the article manufactured and the raw materials from which it is produced are both heavy and bulky, and where there are also large quantities of waste materials to be removed or to be converted into marketable commodities, as in steel and iron and chemical works, breweries, &c.

Such was to a very great extent the position of Messrs. Guinness's Brewery in 1873. As the available ground on the high level at St. James's Gate was all occupied, Fig. 1, Plate 51, and the business fast increasing, an extensive piece of ground lying between James's Street and the River Liffey was purchased, with the two-fold object of obtaining direct communication with the Irish railway system, and with the Port of Dublin by means of steam barges on the Liffey, and of transferring the cooperage, washing, and filling sheds from the old premises to a more convenient site for handling, for which the situation of the newly acquired ground, being on the level of the river quay and some 50 feet below the old brewery, rendered it peculiarly suitable. The facility of delivering from a high level to a lower pointed to the advisability also of discharging the largest waste products, namely grains and spent hops &c., upon the new site. All this work, together with the receipt of the returned empties and the delivery of the stout in barrels, was thus removed from the brewery to the vicinity of the railway and river. The question which then arose was that of carrying on the traffic, not

only within the old and new premises, but also between them and between the new premises and the river and the railway terminus. This was effected by the construction of a double system of tramways, namely: a tramway of 5 ft. 3 ins. gauge, the same as the Irish railways, for communicating with them from the new premises; and a tramway of 22-inch gauge for the work within the brewery and for communication between the higher and lower premises. This narrow-gauge Tramway and the Rolling Stock for working it, which are illustrated in Plates 51 to 65, form the special subject of the present paper. The working of the broad-gauge wagons with a narrow-gauge engine, having been developed by the requirements of the traffic, is also described, being perhaps novel and of some interest.

The subject will be considered under the four following heads:—

1. Design of line; gradients and curves.
2. Permanent way; points and crossings.
3. Rolling stock; locomotives, wagons, and haulage truck.
4. Traffic and signals.

Design of Line.—In designing the line the author set himself to comply with the following conditions:—that as far as possible all the traffic within the brewery should be worked by steam power; that the levels should be connected by gradients not exceeding 1 in 40 and with as easy curves as practicable; that the weight of the engines should be as great as could be obtained upon their limited wheel-base, since the loads to be hauled were considerable, and in addition the gradients were heavy, the curves sharp, and the wheels small; and that the rolling stock should be of as great a capacity as a width of 5 feet and a headway of 6 feet would admit. The first difficulty that presented itself was the difference of level, which had to be surmounted within a very limited area. To meet this difficulty a hydraulic lift had at first been employed, by which the wagons were raised or lowered, one by one, between the two levels. This was a very slow and costly process, involving the separation and making up again of the trains. The author was strongly impressed with the great advantage that would accrue from

connecting the two levels, without exceeding the set gradient of 1 in 40.

Spiral Tunnel.—To meet these conditions it occurred to him that a spiral tunnel might be constructed. Upon investigation this plan turned out to be not so fanciful as it seemed at first; and on working it out it proved to be perfectly feasible. The radius of the spiral tunnel, which is situated at T on the plan, Fig. 1, Plate 51, was settled at 61 ft. 3 ins., with 2·65 turns and the gradient of 1 in 40. The mode of construction was as follows. The earth was excavated from the annular space between two concentric circles, to the depth requisite for the lowest ring of the spiral, as shown in the transverse section of the tunnel, Fig. 39, Plate 64. The sides of this annular excavation were propped, and then the side walls were built up to the top; the spaces between the walls and the sides of the excavation being filled in with concrete as the work proceeded. A strong brick arch was at the same time built spirally from the bottom to the top of the excavation, separating the several laps of the spiral one from the other; and on this arch the rails were laid. The height of the tunnel is 7 ft. 3 ins. from the rails, the width 8 ft. 9 ins., and the thickness of arch 16 inches. A short connecting tunnel was formed at the bottom by driving a heading and lining with brickwork in the usual way. On issuing from the tunnel at the top, the line takes a short stretch to the east, tangentially to the spiral, and forms a junction with other lines; and then returns westwards, passing again over the tunnel in the open, thus forming a third lap, which is on the level of the brewery yard about 35 feet above the rail level at the bottom entrance to the tunnel; as shown in the developed profile of the line, Fig. 2, Plate 52, which has eight times greater scale vertically than horizontally.

Zigzag.—The remaining 15 feet of rise, from the quay up to the bottom of the spiral, is effected by means of a zigzag incline from the quay up to the mill-stream at B on the plan, Plate 51. This road crosses the mill-stream twice, continuing the incline by a small brick viaduct up to the bridge over Cooke's Lane; this bridge

is on the same level as the entrance to the tunnel under James's Street. For the sake of quickness and convenience in working, the line is constructed with curves, no points being used; so that a train can be run from the lowest to the highest level, and over the whole extent of the premises, without shunting or changing the engine to the other end of the train.

Permanent Way.—On this small line the permanent way has undergone some changes, more particularly at those parts where it has been laid with rails above the ground level, which has been done at places where there is not any horse traffic or much other traffic. The first rails were of iron, and as light as 16 lbs. per yard; and the weight has since been increased to 46 lbs. per yard in the present steel rails, of which the section is shown in Fig. 6, Plate 53.

The tram-rail, Fig. 7, Plate 53, forming by far the greater part of the line, is laid wherever there is foot or horse traffic and where paving is consequently required. It is of iron, weighing 56 lbs. per yard, and as shown in Fig. 8 is fastened to rebated longitudinal timbers, which are laid on cross sleepers, and in some cases directly upon concrete, in which case wrought-iron cross-ties are used. The portion most recently constructed has been laid with steel rails weighing 76 lbs. per yard, rolled with web and flange, as shown in Fig. 9, and laid on cross sleepers; the foot is made narrow, in order to allow of its being easily bent to the small radii required. In the laying out of the line, triangles have been so worked in as to form easy means of turning a train whenever required, without uncoupling. Owing to the small radii of the curves in the triangles, very little ground space is occupied for this purpose. Both narrow and broad-gauge roads are now entirely without turntables, with the exception of one only, which is used for placing the engines and wagons over their pits in the running shed at R, Plate 51. As there is horse traffic over the broad-gauge rails on which the railway wagons run, these rails are grooved, Fig. 10, Plate 53, and the wagons run on the flanges of the wheels in the grooves, instead of on the tread, thus keeping the tread of the wheel well clear of the pavement and avoiding the use of a guard rail. The total length of line and sidings is about 5½ miles.

Points and Crossings.—At first the points and crossings were made out of the rails themselves, as on the broad-gauge railway lines. But experience soon demonstrated that in order to make a good permanent job they must be something more than a mere reduction in proportion from the sections used on broad-gauge lines. For switches the tongued point as used on tramways has been adopted for narrow-gauge and tram lines; and the crossings when very close to one another are made of cast-steel rails bolted upon a cast-iron plate with a wood liner between, as shown in Fig. 5, Plate 53. For the broad-gauge tramway, with the necessarily larger radius to suit the rolling stock of the railway companies, the tongued point would be too long and thin; a shifting tramrail is therefore used, which is supported in a tapering cast-iron shoe, only just wide enough to allow for the necessary extent of movement to bring the rails opposite.

Rolling Stock.—The present rolling stock comprises nine locomotives and 177 wagons.

Locomotives.—The first locomotive ordered, shown in Fig. 11, Plate 54, weighed only about two tons and is suitable only for light work. It has the defect that, owing to the gearing being so close to the ground, it is very difficult to keep in order when working full time. Geared engines, shown in Fig. 12, were then procured, weighing about five tons, and owing to their increased hauling power were found very useful; but the absence of springs rendered them costly in repairs and hard on the road. They were also slow in speed and somewhat troublesome in starting.

The next class, weighing six tons and having outside cylinders, as shown in Fig. 13, Plate 54, proved better adapted to the traffic. They have circular ends for foot-plates, and have also water tanks for condensing the exhaust steam. The motion being all outside made it very accessible for cleaning and repair; but being so near the ground it got very dirty, and the wear on this and on the horn-plates from the same cause necessitated very frequent adjustment. In addition to case-hardening those parts usually case-hardened, it was found a great improvement to have the eccentric sheaves and straps case-hardened, and also the big-end crank-pin bearings.

The difficulty in finding an engine suitable for the required duties led the author to apply himself to overcome the objectionable features of these three classes of engines, by designing an entirely new form of engine which should combine the best points of each and avoid their defects. In thinking the matter over, it occurred to him that a good arrangement with springs could be made by placing the cylinders and crank-shaft horizontally above the boiler, and that the motion could be communicated through vertical coupling-rods from the crank-shaft to the main driving axle, the upper and lower axle-boxes being connected together by a link which would keep the centres at a fixed distance.

In the carrying out of this design, sundry difficulties presented themselves. The first of these was the connecting together of the upper and lower crank-pins in such a way as to allow for the oscillation of the two shafts, due to defects in the road, without interfering with the true bearing of the brasses on their respective pins. The question arose how much oscillation it would be necessary to allow for; and it was considered that a play of $\frac{3}{4}$ inch would be sufficient to allow. In the inclined position due to this amount of play, it is astonishing how much out of line the two shafts appear, as shown in Fig. 21, Plate 58. To overcome this difficulty the author adopted the expedient of thinning down the ends of the vertical coupling-rods near the crank-pins, as shown in Fig. 21, so as to allow of their springing, while at the same time making them sufficiently broad, Fig. 20, to retain the necessary sectional area for strength.

The second difficulty was the adjustment required for the wear that was likely to take place in the top axle-boxes, owing to the thrust of the vertical coupling-rods, in addition to that due to the forward and backward thrust of the pistons. This has been overcome by the arrangement of brasses shown in Fig. 19, Plate 58. As the vertical and horizontal thrusts, and consequent wear, are on the whole about the same, the side cod pieces are made to a right angle, so that when adjusted they close in the bearings equally both vertically and horizontally.

A third difficulty that presented itself was how to avoid the use of horn-block guides, which had been found to be a constant source of trouble and expense. It had to be borne in mind that the pull of the engine, the side oscillation, and the thrust of brake-blocks, had all to be provided for. The arrangement shown in Fig. 20, Plate 58, has been found to get over this difficulty. The axle-boxes of the carrying wheels do not slide in horn-plates in the usual way, but have vertical play to the extent that the spring-frame will allow; and the brass linings are turned as parts of a cylinder, Fig. 18, for allowing the axles to adjust themselves in case of an unequal lift on either side of the engine. It will be observed that this bogey has to transmit the pull of the drawbar only, and not the forward and backward pressures from the pistons.

The general design of these locomotives is illustrated in Plates 55 to 57, from which it will be seen that great facilities are given for getting out the wheels and axles, whilst the cylinders and motion being kept on the top are quite out of the dirt and are most accessible for cleaning and repair.

In order to avoid bolting the cylinders to the boiler, the frames F, each in one plate, are carried the full height to allow for stays both below and above the boiler; and the cylinders are bolted in between them, the motion-plate M forming a stay much in the usual way, but above the boiler instead of below. The independent spring-frame S is formed of eight steel leaves in four pairs, two pairs on each side, one pair on the top of each pair of axle-boxes, and the other pair under the bottom; it is attached to back and front stays, so that by removing the pins and coupling-rods, and lifting the engine, this spring-frame with wheels and axles and brake gear can be run out, and every part of it is then accessible for examination and repair.

The upper or crank-shaft axle-boxes are provided with horn-plates, and are each connected with the spring-frame by a link L having the pin in the upper end lengthways of the engine, and in the bottom crossways, as shown in Figs. 17, 18, and 21, Plates 57 and 58, which allows the lower axle-box to lift vertically and the upper one at an angle, thereby giving freedom for oscillation.

The weight of the engine and boiler is transferred to the axles through pillars bearing on plate-springs which are fixed on the spring-frame, one over each axle-box.

The brake gear consists of one cylinder C, Plates 55 and 56, having two pistons, between which steam is admitted. The forward piston puts the brakes on the backs of all four wheels, and the back piston puts the brakes on their forward sides. When steam is shut off, the brakes are withdrawn by the pressure of four springs N, Plate 56. The application of the brakes it will be seen does not bring any strain on the coupling between the spring-frame and the engine-frame. The brake cylinder is made with such a length of stroke that it will just wear out the brake-blocks, which are of cast-iron; so that there is never any fitting or adjustment of the blocks, but they are simply renewed when worn out.

The boiler is of Ramsbottom type, with a barrel 2 ft. 5 ins. diameter inside, having 64 tubes of 2 ft. $10\frac{3}{8}$ ins. length and $1\frac{1}{2}$ inch outside diameter. The heating surface in the tubes is 72·61 sq. ft., and in the fire-box 13·75 sq. ft., making a total of 86·36 sq. ft. The grate area is 3·24 sq. ft. The working pressure is 180 lbs. per square inch.

The cylinders are 7 inches diameter and $8\frac{1}{2}$ inches stroke; and the slide-valves are circular.

The wheels are 1 ft. 10 ins. diameter, on a wheel-base of 3 feet. The weight on the leading pair is 3·6 tons, and on the trailing pair 3·8 tons, making a total weight of 7·4 tons.

The drag hooks D are made as shown in Plate 55, and are centred as near the centre of the engine's length and as low as possible, in order to facilitate passing round small curves. The back and front foot-plates are made with rounded ends, Plate 56, struck from the same centre as the hooks. The hooks are provided with safety bridles or shackles B, to prevent the couplings from jolting out while running; they are uncoupled by simply lifting by the shackle.

Tip Wagons.—A manufacturing firm is differently situated from a public carrying company in having to provide only wagons adapted

to its own requirements, which are more clearly defined and more easily ascertained than when the wants of every description of traffic have to be met. In the case of an existing establishment where the old buildings were not laid out for such a contingency as a railway, the necessarily sharp curves and narrow openings and probably low headways will very much affect the design of rolling stock. In the present instance 5 feet in width, 8 feet in length, and 6 feet in height, on a wheel base of 3 feet, were the limits not to be exceeded with the four-wheel tip wagons, which are illustrated in Figs. 22 to 29, Plates 59 and 60, and are specially designed for carrying grain, coal, ballast, &c., and consequently are well adapted to the requirements of a brewery, or other manufactory where the quick loading and discharging of loose material is required. The object of this arrangement is to get as large a body as possible, and at the same time a sufficiently great angle for the complete discharge of the load. The wagon has a capacity of 80 cubic feet, and weighs 15 cwts. It is without doors and their necessary hinges and fastenings. The body, which is made of $\frac{1}{8}$-inch plate, is suspended on the two end frames F by means of rollers R; and the centre of gravity of the load alone, or of the whole wagon when loaded full, is above the path on which these rollers can move transversely. The body is kept in vertical position by spring fastenings S catching in the castings C on the buffer beams B; and these castings also serve to relieve the end frames from shocks due to shunting. In the diagram, Fig. 24, E is the centre of gravity of the whole wagon when empty, and W when loaded full with water; the centre of gravity of the load alone is at L, and T is the centre of gravity of the whole wagon when the empty body is tipped into the extreme position shown by the dotted lines.

When loading with material to be shovelled from the ground level, the fastenings S are pulled out of the catches C by the chain N at the side, opposite to the loading; and a slight additional pull causes the rollers to rotate, which they readily do, being urged by the extra weight of the upper part of the body. The empty body being thus inclined to one side, the material to be loaded has not to be pitched so high as if the body remained upright;

but as the load accumulates in the bottom, the body becomes vertical again, and the catches are again caught and held by the castings C. For discharging a load, it is only necessary to pull the chain attached to the spring catches until the body is released, and then to give it a slight tilt; and as the centre of gravity W is high, the body will tip itself over until the springs are caught by the top J of the frames, in which position the sloping side of the wagon gives a sufficient angle of discharge for all brewery materials or products, as shown dotted in Fig. 24. The top catches at J are indispensable, inasmuch as, should the material not all run out at the moment the extreme angle of tip is reached, and some portion of it be retained at the bottom, the body will swing back vertical again and the centre of gravity will then be below the centre of the rollers, and a considerable force will be required to bring the body again to the angle of tip and hold it there until the contents are discharged.

The coupling bars, Figs. 25 and 26, Plate 60, are suitable for both pulling and pushing. The centres on which they turn are of course the points vertically and horizontally at which the greatest effort is exerted to pull the wagons off the line when passing round a sharp curve. Consequently the lower these centres can be got and the nearer to the middle of the wagon's length, the better. In this respect the present coupling, although it gives satisfaction, might be improved. Like those of the engines, the wagon couplings are provided with shackles, to prevent them from becoming uncoupled. When the wagon is used for perishable material, a pole is passed through the holes of the bar at each end, and a tarpaulin cover is added over all.

Bogey Wagons.—In addition to these four-wheel wagons for carrying in bulk, wagons are also required for the larger materials which could not be accommodated on four wheels with such a short base. For this traffic a platform wagon mounted on two bogey frames is used, as shown in Figs. 30 to 32, Plate 61. Its weight is about 28 cwts. The bogey, shown in Figs. 33 to 35, Plate 62, is made simply of two longitudinal timbers L resting on the axle-

boxes, with a piece of transverse plate T bolted across, to which is riveted the centre C carrying the platform beams. It was thought advisable to put in side rollers R, so that in case of excessive load on either side the roller will come into play. The coupling bars are at the same height, and the same in every respect, as those used on the four-wheel wagons, and are fixed to the bogeys and not to the platform of the wagon.

Haulage Truck.—This apparatus is designed with a view to enable the existing small engines to be employed, thus saving the expense of two shunting locomotives of the 5 ft. 3 ins. Irish gauge, and avoiding the need of a second shed. It was considered that for the slow speed required one of the small locomotives would be quite equal to the work to be done; and thus far the plan is found to answer its purpose well. The mode of using one of the small narrow-gauge engines for hauling broad-gauge wagons on their own line is shown in Figs. 36 to 38, Plates 63 and 64. The engine is lifted by hydraulic power upon a broad-gauge haulage truck having four grooved wheels G, on which the wheels of the engine rest with their flanges in the grooves; and on the counter-shafts C carrying these wheels are pinions P, gearing into spur wheels S on the axles of the truck carrying wheels. The ends of the two counter-shafts rest in two movable frames F, which bring the weight of the engine upon the truck axles. The weight of the body of the truck is taken on the axles by springs. The weight of the truck is between eight and nine tons, making with the engine about sixteen tons; and the gearing is so proportioned that the speed of the circumference of the tires of the engine is double that at which the whole apparatus travels along the rails, thus giving to the combined engine and truck about double the hauling power possessed by the engine alone. The bearings in the movable frames F are constructed in the same way as in the locomotive already described, and allow of the axles getting out of parallel with each other, but still having a fair bearing in their brasses. There will at times be a very slight degree of twist between the pinions P and spur wheels S; but this does not amount to anything material.

Traffic.—The total traffic at present is about 1,500 tons per day. In most cases the roads have been laid out at the brewery with the view of working in circuits. In the distribution of the empty casks, for instance, an engine with nine unloaded bogey wagons leaves the washing shed at C, Plate 51 ; goes to the repairing shed, where it hooks on in front a loaded wagon and leaves one unloaded ; proceeds to the magazine for new casks, and again hooks on a loaded wagon and leaves one unloaded ; and so on to the different yards and banks for receiving empty casks from the city and canal delivery brought by drays, from the railway delivery brought in wagons on broad-gauge lines, and from the river delivery brought on bogey wagons hauled by horses : until it has gathered nine full wagons in front and has left nine empty ones at the stations to be filled. Now it comes down one side of the triangle at D, and up the other side, past the points which put the engine in front of the load ; and thence goes forwards to the washing shed, where it leaves the nine full wagons it has collected. Here also are the last nine wagons that were left full, but by this time are unloaded. These are now hooked on in front of the engine, which is now reversed ; and it again goes the round as before. In this manner about eight thousand casks can be transferred from their several points to the washing shed in ten hours by one engine-driver and conductor and twenty-seven wagons ; and this is often done in that time, in addition to the return of faulty casks to the repairing shops.

Signals.—These are scarcely needed with such slow speeds and short runs, and are used in only two places, namely a little outside each end of the spiral tunnel. Their construction is shown in the diagrams, Figs. 3 and 4, Plate 52, and is as follows. At each end of the line to be blocked or cleared there is an overhead lever L rocking on a centre over the middle of the line, with a hanging piece of rope attached to its lower end, and a weight on its upper end. The two levers are connected by a wire W, fixed to a point a little above the centre of each ; and two ropes R, one near each end of the tunnel, are hung from this wire to within reach

of the engine-driver. When the two levers lie with their weighted ends inclined towards each other, Fig. 4, the road is clear. When either lever is pulled over so as to lie parallel to the other, Fig. 3, the road is blocked. The weight on each lever is such that, should it be thrown over by the driver entering at one end of the line, a driver at the other end would not have power to pull it back, because he would have to lift the weight at his own end as well as that at the opposite end, and the two together are too heavy for him to do so. The three following cases will explain the working.

First, should a driver entering at one end find that the lever at his end is over with the weight looking towards him, he knows that the line is blocked, and he waits till the driver who has blocked it clears it again: which is done, on leaving the opposite end from that at which he entered, by catching the hanging rope attached to the wire. The pulling of this stretched wire, which is done while the train is in motion, will pull over the blocking lever at the entering end, and will thus clear the line, which cannot be effected by pulling at the lever itself at the outgoing end of the line. The driver who has been waiting then follows, having first blocked the line again himself at the entering end.

Second, should a driver coming to the signal find that the lever is apparently in "line clear" position, he tries to block it; but should he be unable to pull it over, he knows that there is some one coming in the opposite direction who has thrown the opposite lever over to block. He then backs into a siding to get out of the way of the driver coming in the opposite direction, who, when he comes to the rope hanging from the stretched wire, catches it and so clears the line. The first driver then throws his own lever over to block and proceeds.

Third, should two drivers come to the signals at the same time, one at each end of the line, then whoever pulls his lever over first has got the road to himself.

As the men know that their situations and perhaps their lives depend on the regular working of the signals, there is found to be no trouble with them. In the cases of local traffic, like that of the cask-washing and the removal of grains and malt, a conductor

accompanies the train, shifting the points and signalling with a flag; and when passing through the public thoroughfares he carries out the requirements of the Board of Trade and other public authorities.

Discussion.

The PRESIDENT considered the Members might be well satisfied to have come to Dublin, if only to hear this paper. It had been a most interesting one, especially to all owners of large works where large quantities of material had to be moved. It was well known that in many of the large iron and steel works the difficulty was to get the traffic about. In many cases the way in which it was moved made all the difference between earning a dividend or not. Their Past-President, Mr. Ramsbottom, at Crewe, had been the first he believed to take up the question of working the shop traffic there with small locomotives. Most of the Members had seen those small locomotives at Crewe working in and out of the shops on a line of 18 inches gauge, doing very good work; and he thought the distinction which had been conferred upon Mr. Ramsbottom by the University of Dublin, in presenting him with the honorary degree of "Master in Engineering," was a well-deserved honour, if for no other reason than those small locomotives.

This question of moving the traffic seemed to have been taken up in the present paper with a broad view, and to have been so thoroughly considered by the author in nearly every point that it would be difficult to suggest anything which would be an improvement on what he was doing. Although he had himself not yet had the pleasure of seeing the working of the tramways at the brewery, he had been at the Irish Exhibition in London, to which the author had sent examples of his wagons and locomotives,

so as to show his system; and having looked through the details he had been much pleased with the ingenuity displayed in many of them. The tip wagon he thought was a very good plan indeed, overbalancing itself when the catch was released, and throwing the stuff well outside, clear of the line. The arrangement also for enabling the small locomotive to do the work of a large broad-gauge engine, by mounting it upon the haulage truck, he considered was well carried out. The spiral tunnel seemed a much better plan than using hydraulic power, which necessitated stopping and starting; with heavy material it was far better to get a continuous motion if possible. He was looking forwards with pleasure to visiting the brewery and seeing the tramway at work, feeling sure that it had many important applications which engineers connected with large iron works might consider with profit. The amount of traffic moved every day—1,500 tons—would give an idea of what the author had to do, not in a crowded thoroughfare, but in crowded shops, many of them old shops, which had to be dealt with as well as the new ones.

Mr. S. Wilfred Haughton suggested that, in the construction of the latest form of locomotive described in the paper, an improvement might be made by arranging the connecting-rods diagonally from the engine above the boiler to the wheels below, instead of connecting the upper shaft directly with the wheels immediately underneath it. He had himself had to deal with an engine of that kind on the Dublin Wicklow and Wexford Railway, when that line took up the working of a mineral tramway which ran down through the Vale of Ovoca to the harbour of Arklow. The traffic was worked by an engine of the agricultural type, actuating the wheels by means of links. When it came into his hands he removed the links, and substituted connecting-rods in the same way that Mr. Geoghegan had done, but arranged diagonally instead of vertically, in order to get over the difficulty of vertical play. The plan worked remarkably well for many years, as long as the tramway continued in use; he considered it a great improvement on the old connection by means of links. In every other respect he fully agreed with the President in

(Mr. S. Wilfred Haughton.)
thinking that the details of the method described in the paper had been worked out with great attention to all the requirements.

Mr. DANIEL ADAMSON, Vice-President, agreed with the President that 1,500 tons per day was a great deal of traffic to shift with small locomotives, when it had to be done in a confined space and in a fragmentary way; but in an iron works it was a mere nothing, either in weight or in quantity. He had listened with great interest to the paper, because it referred to a number of special adaptations to meet the requirements of the case. The arrangement of the locomotive was particularly good for getting all the wearing surfaces out of the way of dirt, and yet in such a position that the driver could see the moving parts and keep them well oiled. It was true that Mr. Ramsbottom had been the first to adopt the little donkey engine for works purposes; but the boiler shown in the drawing was of much earlier date. He had himself been brought up on the Stockton and Darlington Railway, where for years many of that kind of boiler had been used; it was called the King William class of boiler on account of being originally used there on an engine bearing that name. The engines were built with vertical cylinders on the boiler, and vertical connecting-rods to a dead or intermediate crank-shaft underneath the boiler; and from this crank-shaft the driving wheels were worked by horizontal side-rods. Those engines worked the traffic on the Stockton and Darlington Railway for a great number of years, and performed a great deal of useful work perhaps better than would now be expected; for when he left that railway in 1849 they were carrying all their heavy goods traffic at one-tenth of a penny per ton per mile, including interest on the engines, and wear and tear of the engines and of everything appertaining to them, but not interest on the railway itself. It might be assumed that another tenth of a penny would have paid a moderate dividend on that slow traffic. The old No. 1 engine on the Stockton and Darlington Railway had vertical cylinders in the centre of the boiler, with a cross-beam coupling them together, from the ends of which worked two vertical connecting-rods; but in those days there were no springs. That old engine ran till 1851, having

opened the Stockton and Darlington Railway on 27th September 1825; it started with eight wagons, and it ended with hauling twenty-four, owing to an increase of boiler power. Subsequently the same kind of engine with vertical cylinders was used with box springs, a series of springs placed in a cast-iron box and much compressed. The rails at that time he believed were made of cast-iron, only a yard in length; and it was not an uncommon thing for an engine to get off the line many times in a forty-mile journey. Afterwards, as was well known, a fish-bellied rail was adopted, having its ends flattened in width so as to form a half lap, through which a horizontal spike was driven to hold it in position in a small cast-iron chair; this lasted many years, until greater simplicity, which was always the latest to be arrived at, resulted in the present rail, parallel throughout in depth, jointed in the centre of a longer chair, and fixed by an iron side-key; after which the wood side-key followed, as now in use generally.

The side-tipping wagon was not an uncommon arrangement, and was doubtless specially adapted to the requirements of the present case. He was more especially pleased with the plan of transferring the narrow-gauge locomotive to work the broad-gauge traffic by mounting it on the haulage truck. The President in his address had alluded to the disadvantage of a break of gauge in Ireland. Undoubtedly it would be a very desirable thing if a break of gauge could be avoided; but if there were to be an alteration of gauge, he thought it would be preferable that the reduction should be to $3\frac{1}{2}$ feet. On a $3\frac{1}{2}$ feet gauge he believed that, instead of carrying only a ton for 1*d.* or $1\frac{1}{2}$*d.* a mile, an Irishman with his three pigs and cow besides might all be carried for the same money. He strongly advocated a narrow gauge for Ireland, which he thought was abundant and commensurate with the traffic, and would be far more economical than the broad gauge. A narrow-gauge line, besides being cheaper, was exceedingly suitable for quick curves, round which there was less friction than on a broader gauge. Also there need not be so many tunnels, which did not produce any passengers; whereas, if the line ran round a hill, it would get the passengers dwelling on the surface of the land. For the convenience

(Mr. Daniel Adamson.)
of country districts a narrow-gauge railway he considered was a great gain.

Looking at the subject generally of the paper, he quite concurred with the President that they were all much indebted to the author. There were many other collateral purposes for which the method described in the paper could be employed. One advantage of the Institution meetings was that the Members did not always want to see what they themselves manufactured, but they wanted to see what others were doing, even if quite out of the common groove in which they themselves moved; then they had the means of re-adapting, and, whether they confessed it or not, they were often able to turn to good account for themselves the methods described in the papers read. The paper read by Sir Howard Grubb was instructive in the same way; he had not only shown how to regulate a clock with such great nicety, but he had contrived a governor having sufficient power to effect the regulation. The same idea had occurred to himself and others, and at many works in Lancashire the power of the engine itself was employed for effecting the regulation under the control of the governor: as soon as the machinery underwent the slightest variation in speed, the engine-power came into operation and effected the necessary alteration of the steam-valve, until the proper speed was regained.

It was a great satisfaction to find that economy of power was being studied in breweries, as well as in many other works. If this country was to hold her own against the world, there ought not to be any relaxation of the attempt to meet the difficulties of moving quantities of material in works; and increased consideration should be given to the subject, in order that labour might be reduced to a minimum, and that British goods might still continue to be sent to all parts of the world as the cheapest and best goods manufactured, while yet enabling the best wages to be paid at home to industrious skilled workmen.

Mr. JOHN A. F. ASPINALL had often wondered that similar tramways to those described in the present paper, and to those which, as the President had mentioned, had been early used by

Mr. Ramsbottom in the locomotive works at Crewe, had not been adopted much more extensively in large works than was at present the case. Those who had adopted them he believed had very soon appreciated the advantages of that mode of carrying their materials over a large area of ground. It did not matter so much whether there was a large quantity to be moved; it was the extent of ground over which the material had to be moved that was the important thing. The difficulty lay in transferring moderately heavy weights from workshop to workshop; and the time occupied in doing so, and the money spent on labourers' wages, were what was saved. A large amount of material could be carried quickly from point to point with a tramway of this kind. The manufacturing works of one of the principal locomotive builders near Manchester had lately been laid out with a tramway of 18 inches gauge; and the head of the firm had recently told him that they wondered how it was they had done so long without it, and that having now got it they should be sorry to be without it. In arranging recently the works of the Lancashire and Yorkshire Railway at Horwich he had also had to lay similar tramways, amounting altogether to several miles in length; and a number of small locomotives had been built for them by Messrs. Beyer Peacock and Co., of Manchester, which were a good deal like Mr. Geoghegan's heavier form of engines shown in Plates 55 to 58; though not so heavy as these, they were sufficiently heavy for his own purpose, because the whole of his works was practically level, whereas Mr. Geoghegan's engines had to mount gradients of one in forty. The form of locomotive shown in Plates 55 to 58 had many parts about it which seemed to himself to add to its complexity; but no doubt the author had good reasons for his plans. The tip wagon shown in Plates 59 and 60 he considered was a very useful one. Some years ago through Mr. Geoghegan's courtesy he had been through the whole of the brewery, and had been shown all the details, which were most admirably worked out. The author had certainly taken the greatest possible advantage of the system, and it had been worked out thoroughly well. In addition to other works which he knew were already laid out with tramways of this kind, he understood that a large copper works

(Mr. John A. F. Aspinall.)

now being established was having similar tramways laid down within its premises. Instead of the gauge of 22 inches, adopted by the author, he himself preferred an 18-inch gauge, which gave facilities for getting in and out of the narrow doors of the workshops, and reduced the curves. Nowhere at Horwich were the curves greater than 13 feet radius, which of course enabled the line to be got into nooks and corners that could not be got into with curves of larger radius. One of the disadvantages of the heavier locomotives used by the author was that they required heavier rails. The lighter engines employed by himself enabled him to use rails weighing not more than 24 lbs. per yard, whereby the initial cost of the tramway was reduced. The rolling stock used at the Horwich works was illustrated in Plates 66 to 68, and the leading particulars of the engines were as follows. The cylinders were 5 inches diameter with 6 inches stroke, and 2 ft. $3\frac{1}{4}$ ins. centre to centre. The wheels were $16\frac{1}{4}$ inches diameter, the wheel base 2 ft. 9 ins.; the bearings $10\frac{3}{4}$ inches centre to centre; the frame 7 ft. $4\frac{1}{4}$ ins. long, and the extreme width of the engine 3 feet. The boiler of steel, 2 ft. 3 ins. outside diameter and 2 feet long between tube-plates, containing 55 tubes of $1\frac{3}{8}$ inch outside diameter; the fire-box of iron and cylindrical, 2 ft. 3 ins. long and 17 inches inside diameter. The heating surface 10·42 square feet in the fire-box and 36·12 in the tubes, total 46·54 square feet; the grate area 1·78 square feet. Capacity of tank $26\frac{1}{2}$ gallons. Working pressure 170 lbs. per square inch. Tractive power say 1,412 lbs., or 9·22 lbs. per lb. of effective pressure per square inch on the piston. Weight when empty 2·80 tons; when full and in working order 3·19 tons.

With regard to Mr. Adamson's remark (page 342) about the author's boiler being called a Ramsbottom boiler, it was perhaps a mistake to attach any person's name to anything invented nowadays, because it was so hard to find anything which was really new that he was continually being reminded of the complaint that the thieving ancients had stolen most of our modern ideas.

Mr. W. G. Strype mentioned that, as it had been his privilege to take part in the initiation and early construction of the

extensive works described in the paper, he could well recollect the time when the traffic in the old brewery itself was greatly hampered in the comparatively small and narrow passages in which it had to be carried on in the upper brewery above James's Street, as shown in the plan, Plate 51, before the firm had decided upon the step of extending their premises by taking in the large additional area now included below James's Street. The original conception of that addition was due to Mr. W. W. Wilson, the author's colleague at the brewery, by whom it was propounded, prior to Mr. Geoghegan's arrival at the brewery in 1873, to Mr. George Arthur Waller, the then brewer in chief. It appeared a large step for even so great a firm as Messrs. Guinness to undertake such an extension, and the work was approached with a considerable amount of caution at the time he was in the brewery; and the same caution it was clear, from the description of the works shown in the drawings, had since been pursued with great advantage by Mr. Geoghegan, for it appeared that both the weight of the rails and the dimensions of the locomotives had been slowly and cautiously increased. To some extent the gauge of the tramway had been fixed at 22 inches without certainty as to what the traffic would necessitate in the future; the original tramway lines were simple flat bars of iron $2\frac{1}{4}$ inches deep by $\frac{5}{8}$ inch thick, then largely used in colliery tramways underground; these were used to convey the materials in the excavation of the tunnel and in carrying out the work of filling in the lower portion of the premises. As the traffic became developed, rails of 18 lbs. to the yard were laid, and the small engine referred to in the paper as the first locomotive, Fig. 11, Plate 54, was obtained from Messrs. Sharp Stewart and Co., of Manchester. It was afterwards superseded by the excellent locomotives ultimately devised by the author, Plates 55 to 58, which, although they ran at a considerable pace, had rarely had the experience of running off the line like the earlier locomotives mentioned by Mr. Adamson.

The construction of the tunnel had been rather a difficult work, as it had to be excavated underneath the houses, which were tall structures, particularly one known as No. 98 James's Street; the rear of this lofty building was of a circular form, which was

(Mr. W. G. Strype.)
decidedly a weak form of house to excavate the ground from beneath. The plan adopted in cutting under it, which was devised by Mr. Wilson, turned out to be entirely successful, as no subsidence whatever had taken place in the walls of that rather fragile building. The transverse section of the tunnel, shown in Fig. 39, Plate 64, conveyed generally the plan that was adopted in carrying out the excavation under the houses. It would be observed that by the means adopted it was possible to construct the arch after the side walls had been erected; and in excavating under the loftiest house, the excavation not being a great depth below the surface, the house walls were supported on needles while the two side walls of the tunnel were erected and carried up to the foundation of the house. At the points where the arches ran across, corbelling was incorporated and built into the heart of the brickwork, as shown in the drawing. In that way, without disturbing the needles, the two side walls could be carried up and firmly fixed underneath the foundation of the house; and when the house rested securely on these two side walls, the needles could be safely removed, and the arches could be sprung across last of all.

Sir James N. Douglass, Member of Council, asked what was the nature of the ground, and whether there had been any tendency to slipping.

Mr. Strype replied that it was rather poor clay, which was firm enough in excavation, but presented a tendency to slip as it was taken away. There was also a considerable amount of filling, or made ground, which was passed through, as very few of the old houses had been carried down to a solid firm foundation. The spiral tunnel itself was fortunately all in virgin ground.

In connection with the simple plan devised by the author for using his narrow-gauge engines to work the wagons of the full 5 ft. 3 ins. gauge, it had been suggested, and very properly, that the Irish gauge would have been better if made narrower. The responsibility of the present gauge of 5 ft. 3 ins. lay with English engineers, who had conferred upon Ireland a gauge altogether too wide for the

requirements of her traffic; and he thought it would be well worth while to consider the desirability of narrowing the Irish gauge to the English gauge of 4 ft. 8½ ins. It was a remarkable fact that upon the Great Western Railway of England a profit had only been realised after the conversion of the line from the broad gauge of 7 feet to the 4 ft. 8½ ins. gauge. The same result he thought would apply to Ireland, because it was well known that extensions of the present lines could not be profitably carried out, one of the reasons being that the gauge was too wide; whereas a gauge of 4 ft. 8½ ins. would permit such extensions to be carried out, if it were made the standard gauge throughout the country. Many large chemical works in the North of England, having to deal with heavy raw material of the character and extent dealt with at Guinness's brewery, had railway lines of 4 ft. 8½ ins. gauge traversing them with tolerably sharp curves; those lines were not too broad to carry all their traffic, and when required could introduce into the works with great advantage the full-sized rolling stock of the main lines, bringing materials direct without breaking bulk from where most advantageously obtained to any point of the works where they were wanted. There was but one temptation with which it appeared to him the 4 ft. 8½ ins. gauge might be likely to be accompanied, and which might possibly arise upon the occasion of the completion of the projected channel tunnel. The temptation would be to cut a tunnel or to construct a bridge between England and Ireland, and so to establish what might be called a mechanical union, which he was sure would be of a complete and satisfactory kind.

Mr. Benjamin A. Dobson, Member of Council, had observed in a recent visit to America that a railway could be constructed, if it were carried out on the same principles of construction as obtained in America, for considerably less money than was spent in this country. The great cost of the railways here, apart from the land, was due to the heavy rail, the good metalling, and the thorough drainage of every portion of the line. In America these points were entirely neglected; the rails were lighter, they were placed on sleepers much further apart than was usual here, and there was no

(Mr. Benjamin A. Dobson.)
ballasting whatever; there was simply a little earth raked round the sleepers. He had seen heavy engines going along such lines at a fair speed, where according to the eye he should think there must have been a difference of level of at least two inches between the front bogey wheels and the trailing wheels of the engine; and the way in which the rails played about and the sleepers moved in the earth was simply marvellous to behold. Why the engines stayed on the line he did not know, but they did so; our own engines and carriages would certainly not stay on for many minutes. Nevertheless the Americans were able by that system to extend their railways much more readily than we could do. Their first cost was much less; but when they got a traffic that would compare with the traffic obtained in England they were naturally obliged to strengthen their permanent way by putting in steel rails and proper ballasting; and this they were now doing, thereby bringing up the cost of the renewed railways to nearly the same as in this country. But in the meantime, pending the development of the traffic, he really thought too much money was spent in this country in making railways in accordance with certain requirements of the Board of Trade.

In the present paper he was greatly interested, because in England there were a large number of works covering large areas, where this system of tramway haulage had been entirely neglected. The works at Bolton with which he was immediately connected covered about twelve or thirteen acres of ground all over with buildings, of which some were three or four storeys in height. There was about 70 tons a day of manufactured material to be dealt with, which came in and went out of the yard gate, and had to go round the different portions of the works from one shop to another. The tramway arrangement described in the paper had been devised to fulfil a certain end, and it evidently did so most satisfactorily. He should be glad if it were possible to devise an arrangement for ordinary engineering works like his own, where certain material had to be taken to one shop and thence to another, and to pass more or less backwards and forwards. That was the difficulty in his own works, that the material was not taken straight from one

place to another, but had to be deposited for different operations at different portions of the works. From the perfection of the arrangements carried out by the author, he presumed that there was but little horse traffic in the interior of the brewery. Unfortunately in his own works a great deal of horse traffic was necessary; and in most English works he believed the conditions were such as to necessitate a mixture of horse haulage and tramway haulage. A good many years ago he had tried tramways on the full 4 ft. $8\frac{1}{2}$ ins. gauge; but they had proved such a nuisance that they had to be pulled up. He was now contemplating laying down tramways again, and should do so if he could see his way through the various practical difficulties attending their use. One question was whether the tram rail when laid down could be paved up to and along each edge, the same as tramway rails in a town, without then being dangerous to horse traffic. On a broad tram-rail presenting a polished and slippery surface a horse-shoe would slip, and probably the horse would go down, and a large amount of damage would be done which would go to counteract the benefit of the tramways. No doubt if these tramways were placed in large works in Lancashire, the result would soon be somewhat like that with the telephone; the owners would wonder how they had ever got on without them.

Mr. Arthur Paget, Vice-President, referring to the statement in page 336 that the centres on which the coupling bars turned were the points at which the greatest effort was exerted to pull the wagons off the line when passing round a sharp curve, thought that the wording ought to be the "least" effort, instead of the greatest.

The spiral ascending incline seemed to him to be capable of many applications, one of which he understood was being carried out at the iron tower now erecting in Paris for next year's exhibition. If the author of the paper was the first to bring the spiral incline into use on such a scale, it was desirable that this should be known and placed on record, and that he should have the credit of it.

Mr. Jeremiah Head, Past-President, referring to the question of using both locomotives and horses in works where there was a large

(Mr. Jeremiah Head.)

amount of material to be moved, mentioned that in the large iron and steel works in the Cleveland district twenty-five years ago the internal work was almost entirely done by horse haulage, and in the stables at those places long rows of fine cart horses were almost always to be seen. As the quantities and the weights to be dealt with increased, it became absolutely essential to get locomotives to do the work. The earlier locomotives used for the purpose were geared, very much in the manner shown in Fig. 12, Plate 54; but these were found to be slow in operation, and costly in wear and tear; and soon afterwards the geared locomotives were superseded by direct-acting ones. By and by these were increased in size; and now the common type was a four-wheeled engine with a short wheel-base and cylinders about 12 or 14 inches diameter. With the development of shunting engines, the use of horses had been almost entirely discontinued, and now only one or two were kept for carting purposes. His own opinion was that the two plans could not be worked together advantageously; if a tramway was used with locomotives, the horses would be found to be a great nuisance, and would soon be done away with altogether. The most unsatisfactory way of spending money in works of that kind was in moving material about from one place to another; and the more this could be avoided, the better would be the chance of a profit.

With regard to the haulage truck shown in Plates 63 and 64, he enquired how this plan was found to work after a time, when the tires of the shunting engines had begun to get worn unevenly. No doubt all would be well when the tires were new and all the same size, and all fresh turned; but the tires of shunting locomotives used in works, especially where they had continually to go round curves, became different in size after a time: the tires of the front wheels differing in diameter from those of the trailing wheels, and those on one side of the engine from those on the other, according to how the curves preponderated. If an engine with all its tires worn were mounted on the haulage truck, he should expect it would give a great deal of trouble.

For the gearing in the haulage truck he suggested that helical teeth without shroudings would work better than shrouded

wheels with straight teeth. The latter were objectionable, because the square tips of the pinions were apt, if there was the slightest movement of the axle endways, to mount on the shrouding and break either themselves or it. Also if a nut or anything else should get loose from the locomotive and drop into one of the spaces between the teeth, it was pocketed by the side shrouding, and in going round would cause a smash. Helical teeth moreover were much stronger than straight teeth.

With respect to the specially designed coupling-rods shown in Fig. 21, Plate 58, the thinning down of rods in order to allow of a little play was a device which had been very popular some years ago for the eccentric rods of small engines that worked very rapidly, and was introduced in order to save a joint. Now however they were never used; at least he had not seen them for a long time; and the reason was that the slight side strain on the valve spindle wore the gland oval. It was found better to have a substantial joint of the usual kind. In that case the flat part in the rod was of course exactly at right angles to its direction as shown in Fig. 21; and therefore the objection did not apply in the present instance, in which he did not see any reason why the plan should not do perfectly well.

Mr. Edgar Worthington thought the main question affecting the adoption of a tramway in works was the extra cost which it would entail, in comparison with the saving it would effect. An equally efficient locomotive of the kind shown in Fig. 13, Plate 54, he thought might perhaps be constructed at a less cost. In the author's latest engine, shown in Plates 55 to 57, he entirely appreciated the advantage of placing the motion high up, out of the dust and the splashing from the wheels; but an engine such as was shown in Fig. 13 might also be protected from the dust by placing a thin sheet-iron plate underneath the axles, extending the whole length and width of the engine, and bolted to the bottom of the horn-blocks with existing nuts; that was a simple thing to do, and would prevent any of the splashings from the rail and wheels from getting to the motion. If there were any other advantage in placing the motion higher,

(Mr. Edgar Worthington.)
it consisted in affording readier access to the cylinders; it was evident that the parts were exceedingly accessible in Fig. 14, and at the same time removed from the dust.

With regard to mounting the narrow-gauge locomotive on the broad-gauge haulage truck, he asked whether the running of the engine on the tramway alongside the railway, and using a rope to pull the wagons on the broader gauge, would not be more handy than having to lift the locomotive by a crane and deposit it upon the friction wheels on the haulage truck. No doubt one advantage of the present plan was the increased tractive power, owing to the larger purchase through the geared wheels on the truck; and perhaps this might be the reason which had determined the adoption of the plan. In dealing with a large number of barrels, chiefly oil barrels at the works of the Standard Oil Co. in Cleveland in the United States, and also in the large oil warehouses in Jersey City, the full barrels of oil were transferred down descending inclines, which of course was a much cheaper way of conveying them than the method described in the paper. Where the whole traffic was in one direction and of one uniform kind, which could be rolled along on parallel rails or be dealt with in any other simple way, perhaps that would be a cheaper and more efficient method than by means of tramways; but where the traffic was varied and had to be transported in trucks, it was evident that tramways, as had been so fully shown by the author, formed the best method of dealing with a large amount of traffic in extensive works.

Mr. R. HERBERT LAPAGE considered that the 5 ft. 6 ins. gauge of railways in South America was a very good one; and the Irish gauge of 5 ft. 3 ins. he thought was much better than the English of 4 ft. 8½ ins.; it allowed of a great speed and of running much more safely. It afforded facilities for building large bogey-carriages, which there was no doubt ran more safely. Having been in a good many accidents himself, he had found that, although the bogey carriages might run off the rails, they never turned over, while the small wagons turned completely over. The bogey carriages on the 5 ft. 6 ins. gauge were about 52 feet long, and he thought

they could be built much longer still, say up to 70 feet. If a narrower gauge than 5 ft. 3 ins. were desired in Ireland, he should prefer to leave the existing gauge as it was and narrow down at once say to a metre gauge of 3 ft. $3\frac{3}{8}$ ins., as the transferring of suitably designed stock from one gauge to another was not a difficult affair.

With regard to the engine designed by the author, he might suggest that if it were compounded a great deal of economy in fuel would be gained. The Manchester Bury and Oldham tramway had now a compound engine running on Mr. Worsdell's system, with high and low-pressure cylinders of 9 inches and 14 inches diameter respectively, which was competing with ordinary engines of the same type in other respects, and was found to save 20 per cent. both in fuel and in water. There seemed no reason why the author's engines, though smaller, should not be compounded in the same way, and thus be able to expand the steam much better in the two cylinders. Compounding was now being extensively carried out in large locomotives, of which there were already between two and three hundred running on various railways; and there was no reason why the same plan should not be adopted for tram engines.

Mr. A. Basil Wilson said the question of hauling goods on tramways resolved itself into two parts: one was the reduction of friction and of hauling power, due to the fact that the tramways offered less resistance than roads to the transport of goods; and the second was the adoption of locomotives, in preference to horse or manual power. The author's tramway through the brewery was a typical example of the perfection attained by the use of locomotives in dealing with considerable quantities of goods, which had to be transported through a definite cycle of processes, and which consisted of definite classes of material, such as casks, grain, coal, or whatever else it might be. In a case of that kind the adoption of locomotives was especially advantageous. As the Members were about to visit Belfast two days hence, he would refer to the system of tramways which they would there see adopted throughout the shipbuilding works of Messrs. Harland and Wolff. The material

(Mr. A. Basil Wilson.)

there to be dealt with was widely different from that met with in a brewery or in an ordinary manufactory. The lengths to be transported varied from 10 or 20 feet in the case of plates up to 80 feet in the case of logs of timber; and it was necessary therefore to have a special arrangement for the transport of long pieces round corners and underneath and about different parts of ships. Furthermore there was no regular stream of unmanufactured or partly manufactured goods in one particular direction. Naturally the unmanufactured materials came in at one end of the yard, and ultimately left in the form of ships; but in the process of manufacture they had to pass to and fro in a course which was not strictly continuous. In that case therefore the use of locomotives was impracticable, because in the first place it would be impossible to employ a train of trucks for conveying such long pieces of timber; and in the second place the transfer over the turntables would involve considerable delay. Accordingly the plan adopted was to lay the lines of rails more or less at right angles, with turntables at convenient positions. The long balks of timber were laid on two bogey trucks at a considerable distance apart, perhaps 40 feet. When the front truck came to the turntable, it was turned a quarter round and run off along the line at right angles on one side or the other, whilst the rear truck still remained on the other line; consequently in this position the balk of timber extended diagonally across from one line to the other, cutting off the corner occupied by the turntable. By that means timbers could be dealt with of great length, without occupying more room than was involved in the curve they took when passing the turntables. It was occasionally necessary to put three trucks underneath the longest timbers, in order to support their weight in the middle and prevent them from sagging; in that case of course the middle truck had to be removed for passing over a turntable. It was necessary to use hand power entirely for shifting the trucks in a ship yard; but there was less disadvantage in doing so, because every piece that had to be transferred had also to be slung individually in a different way for going to machines, punching presses, mills, or ships. Therefore the squad of men who attended to each pair of trucks pushed them

along by hand power and transferred them over the turntables, passing them on to their respective destinations in the works.

In reference to a reduction of gauge on the Irish lines to the English standard, he believed that on the Great Western Railway the reduction of gauge from 7 feet to 4 ft. 8½ ins. had been brought about in a gradual way by laying a third rail for the narrow gauge inside the broad gauge, the difference of gauge being large enough to allow of doing so in a manner which was compatible with the existing points and crossings of the broad gauge. But in the reduction from the Irish gauge of 5 ft. 3 ins. to the English gauge of 4 ft. 8½ ins., if the same method were followed, the new third rail would come so close to one of the existing rails that there would be great difficulty, and indeed he questioned whether it would be found practicable to arrange a third rail so as to continue the traffic during the transfer. The reduction would therefore mean an absolute cessation of traffic during the time that the change was being effected. In America in one or two cases a line had been stopped entirely for a couple of days while one of the rails was shifted inwards throughout the whole length. That he feared would form an obstacle to any alteration of the Irish gauge, unless it might possibly be altered to a still narrower gauge than the English.

The President mentioned that the South Wales section of the Great Western Railway had all been altered by shifting one of the rails inwards; and by narrowing first the up line and then the down line the whole length of 208 miles right through from Swindon to Milford had in that way been narrowed in May 1872 without stopping the passenger traffic. It would pay Ireland, he thought, to stop a week's traffic, if necessary, in order to get the gauge altered to 4 ft. 8½ ins.; because then, instead of having to procure locomotives and rolling stock of the exceptional gauge of 5 ft. 3 ins., the Irish railways could provide themselves with those of standard gauge which were being built in any of the shops in England at the time.

He proposed a hearty vote of thanks to Mr. Geoghegan for this paper, in which he was sure the Members had all been as much interested as himself.

Mr. GEOGHEGAN thought he had seen the small locomotive mentioned by Mr. Haughton as working on the Arklow tramway some time ago (page 341); and he believed there were no springs on it, and in consequence the two engines could hardly be compared, except in the one particular mentioned of the coupling-rod. With springs the diagonal coupling-rod would not do so well as vertical.

The amount of traffic carried on in the brewery he knew was not anything like what it was in iron and steel works (page 342). He had merely mentioned the actual quantities in order to give some idea of what the tramways and rolling stock were doing. The locomotive boiler he had always heard called the Ramsbottom type; but the King William type spoken of by Mr. Adamson was probably the more correct designation.

The curves used in the brewery on the broad-gauge line of 5 ft. 3 ins. gauge were as sharp as 50 feet radius, and worked very well; the railway wagons ran round them without trouble and without getting off the line. In Dublin and other places where there was no very heavy traffic he did not see why tram lines could not be used to connect the railway termini: he had often wondered they had not been.

On the 18-inch gauge which was preferred by Mr. Aspinall (page 346) he had mentioned that he used curves of 13 feet radius. On the brewery tramway of 22 inches gauge there were curves of only 12 feet radius: so that in this respect perhaps the 22-inch gauge was nearly as good as the narrower gauge.

The first locomotive used on the brewery tramway had been ordered by his predecessor Mr. Strype (page 347); and except that it was now too light for the present work, it had done its work fairly well. The motion could of course be protected by a plate underneath, in the way suggested by Mr. Worthington (page 353); but that would not get over the wear and tear of the horn-blocks, which were one of the worst features in these small locomotives; when once the horn-plates got worn the gearing was all rattling about. The engines of the new type had rarely got off the line, and had never turned over.

Although he agreed with Mr. Strype (page 348) that the Irish gauge was unnecessarily wide and that the English gauge would have been a better gauge for Ireland, still, as far as tramways were concerned, he thought if the ordinary railway rolling stock of 5 ft. 3 ins. gauge could get round a curve of 50 feet radius on a tramway there was not much to be said against the Irish gauge in that respect. The section of tram rail used for going round these sharp curves was shown in Fig. 10, Plate 53, and the groove in the top of the rail was made specially wide, so that on these curves there might be plenty of freedom, and the wheel flanges might not bind in the rails. The section of rail that was in use when he went to the brewery was similar to that shown in Fig. 7, Plate 53, and of the same weight, but of steel and with a central groove; and it had done very well. Of course the wear on the flanges of the wheels which ran in the grooves of such rails would wear them down too small if they ran over any long distances; but as there were so many wagons running over such a short length of tram line, the flanges were not appreciably worn, and they had given no trouble. He had never had a split rail, even in the lightest section weighing only 46 lbs. per yard, shown in Fig. 6, Plate 53.

In regard to laying out these small lines for factories, so that the material could be moved in a systematic way from one process to the next (page 350), this could easily be done where the shops were all laid out at one level, without storeys or different levels; and even for different levels, such small lines could dip down six feet easily, and the gradients were often so short that even with an incline of 1 in 10 a train carrying any quantity of materials would have only half its length at a time on the incline, and would thus get over it without being brought to a standstill. At the brewery there was a good deal of horse traffic mixed up with locomotives, and there had never been a serious accident of any sort with the horses. The only bad accident that had occurred had been that an engine driver, having been too careless in going round one of the curves, had been killed.

In reference to the points of attachment of the coupling bars to the wagons (page 351), what the statement in page 336 was meant to

(Mr. Geoghegan.)
convey was that, in going round curves with considerable tension on the drawbar, the higher the coupling was placed the more risk would there be of pulling the wagon next the engine off the road; and the lower the coupling, the less would be the risk of doing so; if it were down as low as the rails, it could not pull the wagon off the road at all, unless the flanges of the wheels were very slanting. Looking at the drawbar in plan, when the wagons were going round a curve of 12 feet radius, their ends overhung the rails so much that the drawbar was inclined at a considerable angle to their centre lines; and for that reason the longer the drawbar was made, and the nearer its point of attachment was brought to the centre of the wagon's length, the less tendency would there be to pull the wagon sideways off the rails. As mentioned in the paper, the present couplings might be improved in this respect; and he should prefer to make all the wagons like the locomotives, with long coupling bars attached as near the centre of the wagon's length as they could be got.

The spiral tunnel had been designed by himself in 1876, and it was carried out in the course of 1877 and 1878 at a cost of about £3,000.

With regard to uneven wear of the tires of the shunting engine affecting its usefulness when mounted on the haulage truck (page 352), with the old iron tires that would no doubt have been the case; but with the steel tires now used he thought there was no risk of their wearing unevenly, especially as the engine got turned round on a triangle, and so equalised the wear on both sides in each double journey. At present however the plan was so new, having as yet been worked only three months, that it was difficult to say more than that no hitch of any kind had thus far occurred.

The PRESIDENT enquired whether there was any slip in the working.

Mr. GEOGHEGAN replied that the only slip occurred on the rails when it rained, not on the wheels of the engine. The friction wheels were so well covered by the engine that if it rained the wet did not get on them.

Helical teeth (page 352) for the pinions and spur wheels of the haulage truck would perhaps be rather better, and he had indeed thought of them for the purpose; but the work was wanted to be done quickly, and he could not get the patterns in time. The reason for designing the haulage truck had been in order to get the increased hauling power due to its weight in addition to the weight of the locomotive mounted upon it, as it had to haul four broad-gauge wagons, each weighing about 12 tons, up an incline of 1 in 70, with curves at either end of 50 and 70 feet radius. The cost of the haulage truck had been £450.

The thinning down of the ends on the vertical coupling rods of the locomotives he was aware was not new, and it was not essential to the design of the engine. It answered very well, and he had just built three more locomotives on the same plan, in which the same thing had been done. In these the coupling rods were made of spring steel, instead of Bessemer steel; one of the earlier rods of Bessemer steel had broken, but it had been repaired and he thought it would still last well. On the whole he considered the thinning of the ends had proved satisfactory in the present instance.

He had often thought of moving the casks in the cooperage by slides, as mentioned by Mr. Worthington (page 354); but there were so many different sizes to be dealt with that he had never been able to hit on a good plan.

As to compounding, which had been recommended by Mr. Lapage (page 355), the amount of coal used in these shunting engines was so small, only 1 to 2 cwts. a day, that it was hardly worth while to compound them, on this account at all events.

In regard to turntables, which Mr. Wilson had mentioned as used at Messrs. Harland and Wolff's at Belfast (page 356), it appeared to him that sharp curves of 12 to 20 feet radius would do just as well, and could be more easily worked.

In regard to cost (page 353), the first locomotive, shown in Fig. 11, Plate 54, weighing only about 2 tons, had cost £445. The geared engines weighing about 5 tons, shown in Fig. 12, cost £366. The outside-cylinder engines, shown in Fig. 13, weighing 6 tons, cost £597. The latest engines, shown in Plates 55 to 57, weighed

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$7\frac{1}{2}$ tons and cost £848. In the diagram, Fig. 40, Plate 65, was shown the value of the rolling stock and the cost of repairs for the last thirteen years; and it was interesting to notice that, although the value had risen from £7,683 in 1882 to £11,855 in 1887, the cost of repairs had remained practically constant since 1882.

DESCRIPTION OF THE FRICTIONAL GEARING USED ON A DOUBLE STEAM DREDGER IN THE PORT OF DUBLIN.

By Mr. JOHN PURSER GRIFFITH,
President of the Institution of Civil Engineers of Ireland.

The double Steam Dredger No. 4 in the Port of Dublin was built by Messrs. Thomas Wingate and Co. of Glasgow in 1871, and at that date was one of the largest dredgers afloat. Both sets of dredge buckets, the hoisting gear for the ladder, and the fore and aft winches are all worked by a single-cylinder low-pressure condensing side-lever engine of 150 indicated horse-power. It will be readily understood how necessary it is to be able at will to disconnect the gearing of either set of buckets from the main engine, or to raise the bucket ladders and warp the dredger about without driving the upper tumblers.

Grooved Gearing.—To meet these requirements the builders adopted Robertson's grooved frictional gearing (Proceedings 1856, page 202), as shown in Figs. 1, 2, and 3, Plates 69 to 71. Two grooved pinions P of 54 inches diameter, with nine grooves cut to an angle of 40° and $1\frac{3}{4}$ inch pitch, were fixed on the engine shaft E, and geared into two grooved wheels W of $127\frac{1}{2}$ inches diameter, running on intermediate shafts S but not keyed to them. Each of these wheels revolved on an eccentric gun-metal bush B, embracing the intermediate shaft and turning freely on it; and by means of long levers L connected with the eccentric bushes the grooved wheels could be put in and out of gear with the pinions on the engine shaft. A cast-iron driver D keyed on the intermediate shaft was connected with the grooved wheel by a pin and sliding guide-block G, in such a manner as to allow of the eccentric motion; so that when the grooved wheel was thrown into gear it carried the cast-iron

driver round with it, and thereby turned the intermediate shaft S, on which was keyed a toothed pinion N gearing into the large spur-wheel U of the upper tumbler. Thus at will either or both upper tumblers could be put in and out of gear without stopping the engine. The speed of the grooved wheels at their circumferences was about 500 feet per minute. If half the engine power were transmitted by each set of gearing, and allowance be made for the friction of the engine itself, the tangential force at the rims would be about 3,960 lbs.; requiring, if the angle of the grooves were 40° and the coefficient of friction 0·18, a pressure of 7,524 lbs. between wheel and pinion to prevent slipping.

The dredger began dredging in Dublin in 1872, and worked on the average forty-seven weeks per annum for eleven years till 1883, when it was sunk by collision, having raised nearly 4,500,000 tons. The large friction wheels W were practically worn out, and the pinions P had been twice renewed and also re-turned, at a cost of nearly £300. A renewal of the rims of the large wheels, which were separate castings from the bosses and arms, would have cost at least £200. The life of the pinions may be taken as five years, and of the wheels twelve years; and these relative durations are found to be nearly proportional to the circumferences of the pinions and wheels. The cost of repairs and renewals of the grooved gearing, if the wheel rims had been renewed, would therefore have averaged about £47 per annum, or £1 per working week.

Some of the difficulties experienced in connection with this grooved gearing arose from variations in the hardness of the castings. Soft spots wore faster than the hard portions; and by degrees there was a tendency to slip at the soft spots, unless the wheels were kept in gear by very considerable pressure. As the large wheels wore down, the rim deflected between the arms; and this also caused unequal wear, which was attended by slipping of the gearing. In No. 4 dredger the pinion P was wider in the face than the large wheel W into which it geared, and was placed below it, as shown in Plate 70. The oil from the upper bearings trickled down the large wheel, and lubricated the outer grooves of the pinion. The wear and tear of these outer grooves was therefore less than of the intermediate

grooves. This led to their having a greater share of the pressure than the central grooves, and resulted in the outer faces bursting off.

In addition to the mere angle, the form of the groove is an important feature in grooved gearing. When wheels of unequal diameters work into each other, it must be borne in mind that the small wheel will wear faster than the large; and the shape of the grooves in both wheels should be such that they will remain similar in shape till the tops of the ridges begin to touch the bottoms of the grooves, Fig. 4, Plate 71. As soon as this point is reached, the wheels must of course be re-turned or renewed. The practice of cutting the ribs with a uniform slope down to the bottoms of the grooves is objectionable, for, as the upper portions of the ribs wear, shoulders are formed in the sides, as shown in the section, Fig. 3, Plate 71; and on these shoulders the ends of the ribs of the adjoining wheel begin to bear, instead of on the sloping surfaces. Increased pressure has to be applied to keep the wheels in gear, and the advantages of the grooving are lost.

In 1885 and 1886, after the dredger had been raised and repaired, it was worked for a short time with the same frictional gear; but the large wheels were so worn that their rims cracked in several places between the arms. After carefully considering the question of renewal, it was decided by Mr. Bindon B. Stoney, the Chief Engineer of the Dublin Port and Docks Board, to adopt the arrangement shown in Figs. 5, 6, and 7, Plates 71 to 73.

Spur Gearing with Brake-Wheels.—In place of the grooved pinion and wheel, a toothed pinion P is keyed on the engine shaft E, gearing into a spur-wheel W which runs loose on the intermediate shaft S; and to the side of the spur-wheel is bolted a cast-iron brake-wheel K. As in the original arrangement, a cast-iron driver D is keyed on the intermediate shaft. At each end of the driver is hinged a T shaped lever T, Fig. 5. To the short arms of the lever are attached with adjusting screws two steel brake-bands B, the other ends of which are fastened in a similar manner to the corresponding T lever at the opposite end of the driver. The steel bands B thus embrace the brake-wheel K like a brake-strap. The long arms of the

T levers are connected by tension rods R with bell-cranks J hinged at the centre of the driver; and the bell-cranks are also connected with a collar C sliding on the intermediate shaft and revolving with the driver. The collar can be moved backwards or forwards along the shaft by a long lever L worked by a hand-wheel and screw H, so as to loosen or tighten the steel bands on the brake-wheel. When the engine is working, the large spur-wheel W and its attached brake-wheel K revolve; and by tightening the steel bands till they grip the brake-wheel, the driver and intermediate shaft S are set in motion, together with the upper tumbler and its chain of dredge buckets.

The diameter of each brake-wheel is 88 inches, its breadth 6 inches, and the speed at its circumference about 400 feet per minute. In regular work the steel brake-bands are supposed to transmit half the engine power. Each set of gear however is designed of sufficient strength to transmit the maximum power which the engine can exert: that is, on the supposition that the engine may be pulled up at half stroke with the full steam-pressure and vacuum on the piston, and with only one set of friction gear in operation. In practice the brakes slip before any such stress is reached, as they are only tightened sufficiently to start the drivers and buckets.

The whole apparatus is simple and effective. Its wearing parts are accessible and easily renewed at small cost. Engineers having charge of machinery naturally take special interest in the cost of maintenance, which is sometimes overlooked by designers and manufacturers. The importance of reducing wear and tear in dredging machinery will, it is thought, sufficiently justify the foregoing description of a detail which occupies a prominent position in the working of dredgers.

Discussion.

The President said this practical paper, giving the result of Mr. Griffith's experience in the working of dredgers over many years, was of a kind which the Institution always welcomed, because such experience as the author had gained and had here placed before the Members could not fail to be valuable to mechanical engineers in general, whether directly concerned with dredgers or not. It showed that the question of cost in frictional gearing was very much a question of durability of surfaces, and that their durability was in proportion to the circumferences of the grooved wheels which geared together.

Mr. Bindon B. Stoney said the number of buckets that could be raised per minute with the original grooved frictional gear had been twelve: with the modified brake gear the number was fourteen, with a rather less consumption of coal. This of course was a great advantage, as it increased the efficiency of the dredger by one-sixth. A further objection to the grooved frictional gear, in addition to those which had been mentioned in the paper, was that, when it got out of order and the rubbing parts were much worn, it required a great deal of effort to put it in and out of gear, and the act of doing so was attended with more or less risk to the engine-driver; in fact, one of the men operating on it got one of his hands rather severely injured, and that had been a principal reason for considering how the method of driving could be improved. Another advantage of the present mode of driving was that it acted perfectly as a friction brake, in case the dredger came against some obstacle which made it desirable to pull up the engine gradually rather than have something give way. On such occasions the brakes slipped a little; and being put in and out of gear several times every day, they were invariably in good working order. The ordinary arrangement of safety brake which was used in dredging machinery, as most engineers were probably aware, consisted of brass blocks forced by screws into contact with the circumference of a drum. These frequently were not slipping

(Mr. Bindon B. Stoney.)

for weeks or months together; and the result was, according to his experience, that they invariably got locked, and ceased to act at the critical moment. The friction brake now described could not get out of order, and this constituted an additional advantage in its favour. The effort to put it in and out of gear was so slight that a child could do it. It generally took three or four seconds to put it into gear, and rather less to put it out.

Mr. Daniel Adamson, Vice-President, had read the paper with a view to its being communicated to the Institution, and had concluded that, although it was not a long one, it was thoroughly practical and valuable, because as an engineer the author had confessed his troubles and made known the failure of frictional gear. Frictional gear when at its best was properly so named, because it then was truly a method of gearing by means of friction. But where the frictional surfaces passed through only 500 feet per minute, or say 8 feet per second, the plan was utterly inapplicable, because it could never be satisfactorily adapted to such a slow motion. If locomotive driving wheels had to run at the same low rate, very little work would be got out of the engine. In the present case, if the frictional surfaces had run ten times as fast, with the loads correspondingly reduced to one-tenth, the wheels would have had all the adhesion wanted, and would have lasted a great deal longer than it was possible for them to do with slow and heavy loads. A further practical lesson taught by the paper was in regard to the want of uniformity of metals, and also how they suffered when subjected to compression beyond a certain point. The larger grooved wheel W shown in Fig. 1, Plate 69, would no doubt have been much more durable if there had been double the number of spokes for giving greater support to its circumference. Whilst congratulating the author on having removed the frictional gear and substituted spur gear, he would point out that, with the large experience of spur gear which most engineers had in Lancashire, they would not think of running such wheels under 30 feet per second, instead of only about 400 feet per minute or say 7 feet per second. This slower speed however when using spur gear was merely a question of

strength. If the slow speed was the object that had to be attained, the strength of the wheels must be made commensurate with that slow rate. But if it was required to utilise the full power of a spur wheel, and to get such a duty from it as was consistent with its diameter and pitch, then certainly instead of running in practical work at only 7 feet per second it would be wiser to run up to at least 30 feet per second. Lighter wheels could then be used for running at the higher speeds, while at the same time they would be much more durable. The substitution of the brake for the common frictional clutch he thought was wise; it was a change from a small surface to a large one, and the employment of a large drum altogether encircled by a brake-strap was to his mind the perfection of the method of getting friction and letting go, without great stress or wear and tear. For his own part he was especially thankful to anyone who had the courage to confess that things had not done as well as they ought to have done, and that substitutions had been made which had always done better. There were two lessons to be learnt in all such cases: something to avoid, and something to imitate. In the present instance the thing to be avoided was the use of frictional gear with a slow speed, and a heavy load of more than 3 tons in order to produce friction enough to prevent slipping. The thing to be imitated was the better plan of employing spur gear for the purpose intended.

The use of helical teeth for the geared wheels he considered would be advantageous in the present instance, as in many other cases; and his own experience was that the helical teeth were growing rapidly into favour for all practical purposes, because they gave a screw motion. In a planing machine, for instance, instead of having the tooth-marks right across the work, as was the case with straight spur gearing, wheels with helical teeth took hold and let go over a larger extent of their circumference, and the result was a smooth surface with no tooth-marks on it. The helical teeth had also the advantage of increased strength, and an increased extent of surface to resist wear and tear. From his own experience in their use he believed that under a heavy load the driving pressure on the teeth of the pinion or smaller wheel ought to be arranged to come

(Mr. Daniel Adamson.)
on their convex face, because the pinions necessarily wore faster than the larger wheels with which they geared; and therefore, instead of the tendency being to pull the pinion teeth out, as would be the case if the pressure came on their concave surface, it was desirable that the contact should be on their outer or convex surface, in order that they might be under compression in working. He had known a case latterly where a pinion working under a heavy pressure had had to be changed, the teeth having suffered so much from the contact on their concave faces. Since the change had been made, so that the pressure now came on the convex surface of its teeth, the pinion had worked with great satisfaction, and there had been no trouble at all.

Mr. Jeremiah Head, Past-President, had had some experience with frictional gearing of almost identically the same form as that shown in Fig. 2, Plate 70, but used for a different purpose. Sixteen years ago Mr. B. L. Lauth of Pittsburg, America, had introduced into this country three-high rolls for rolling plates; * and he had himself put down a mill on that plan, the middle roll being smaller in diameter than the other two. As the bottom roll only was driven, it was believed that, when the plate came back between the top roll and the middle roll in its return pass, it would slip and stand still, if it had to be driven entirely through the friction of the middle and bottom rolls. Consequently a cage of three-high grooved friction pinions, of the same diameter as the plate rolls and almost as long, was put at the end of the train, and coupled to the plate rolls as regarded the top and bottom rolls, the grooves in the friction pinions being just like those shown in Fig. 3, Plate 71. The plan seemed to work well at first; but in a short time the grooves were found to wear precisely as had been described, first of all by making shoulders on their sides, and then by the points of the ridges bottoming in the bottoms of the grooves; then they had to be taken out and re-turned. But while they were wearing, it was necessary to screw the tightening screws down tight, in order to get the requisite friction; and this was found to be so much against the

* Journal of the Iron and Steel Institute, 1872, vol. 2, pages 86 and 353.

engine that it took almost as much power to drive the pinions as the plate rolls when in action. Eventually a trial was made of doing away with the grooved gearing and running the mill without it; and it was found that when the gearing was discontinued the difficulty which had been anticipated did not really exist: the rolls were driven perfectly well without any gearing at all. It was desirable however to reduce the plates more in the roughing rolls, so that by the time they entered the finishing rolls they were tolerably thin and not too hot.

Mr. John A. F. Aspinall had had some experience of grooved friction wheels for driving a saw for cutting steel ingots, and in that case the frictional gearing gave a great deal of trouble: it was always wearing down exactly in the way described by the author, and ultimately the engine and all the gear connected with it were taken away, and replaced by an arrangement for driving the saw direct. In another case, where the grooved gear was used for a crane, it had little work upon it, being used only occasionally, and it there did very well. For work of that kind, which was light and only occasional, the grooved gearing was perhaps a handy form of mechanism; but the surface contact was so small that, if any hard work was put upon it, it simply wore out too rapidly to warrant its being continued.

Mr. Griffith had been specially interested in the remarks of Mr. Adamson and Mr. Head, and their experience seemed to bear out in every particular the views he held himself. Mr. Adamson had pointed out that grooved frictional gearing might be suitable for high speeds and low pressures, but was unsuited for such low speeds and high pressures as were mentioned in the paper. From all he had read about the grooved gearing, he thought it only just to Mr. Robertson, the inventor, to say that all the evidence seemed to show he had originally intended it only for high speeds and low pressures. It was now sixteen years since this dredger began work, and it might perhaps have been thought that the grooved gearing had now become obsolete for such a purpose; but this was not the

(Mr. Griffith.)
case, for the new large dredger for Swansea, recently illustrated in "Engineering" (13 July 1888, page 45), was fitted with grooved gearing apparently identical with that described in the paper.*

Upon the estimate given in the paper of 7,524 lbs. as the pressure between wheel and pinion necessary to transmit a tangential force of 3,960 lbs. at the rims, he had expected some criticism, because this pressure was much greater than the advocates of frictional grooved gearing would probably allow. At the time when his gearing was first introduced, Mr. Robertson himself had claimed a tangential or driving adhesion amounting to one and a half times the radial pressure holding the wheels in contact: in which case the pressure in the present instance need only have been 2,640 lbs., instead of 7,524 lbs. No qualification had been made by Mr. Robertson for the angle of the grooves, and in his original paper read to this Institution (Proceedings 1856 page 202) the above proportion seemed to be associated with an angle of about 50°: while Professor Rankine in his "Applied Mechanics" (1858 page 618), when referring to these results, had associated them with an angle of 40°, adding however the explanation that "this proportion is much greater than that due to ordinary friction, and must arise partly from adhesion." From some experiments carried out in Dublin on the friction of grooved surfaces he himself believed that the assertion that grooved gearing was capable of transmitting a tangential force of $1\frac{1}{2}$ times the radial pressure could not be sustained as a general claim for all angles. On purely mechanical principles $T = \mu\, P \operatorname{cosec} \frac{\theta}{2}$; where $T =$ tangential force transmitted, $\mu =$ coefficient of friction, $P =$ radial pressure keeping the wheels in contact, and $\theta =$ angle of the grooves. If it were the case that in grooved gearing $T = 1\frac{1}{2}\, P$, irrespective of the angle of the grooves, the extraordinary conclusion would be arrived at

* Since the Meeting the author has been informed by Messrs. Fleming and Ferguson of Paisley, the builders of the Swansea dredger, that they had to supply the grooved gearing because it was specified, but that all their experience is against the use of this gear for main drivers, and they themselves would never adopt it or recommend its adoption. They find that frictional gearing answers well for other purposes, such as hoisting &c.; but where it has been tried for the main gearing it has given more or less trouble.

that the coefficient of friction varied with the angle. For Mr. Robertson's frictional clutches however the angle generally used was 14°; and it seemed not improbable that the results which were now associated with grooved gearing generally had originally been obtained from grooves cut to the angle of 14°. This presumption was supported by the fact that on taking $\mu = 0 \cdot 18$ and $\theta = 14°$ the above equation would give $T = 1\frac{1}{2}\ P$; and it was still further supported by Mr. Robertson's statement (Proceedings 1856 page 209) that the adhesion with his grooved gearing was about nine times that with plain surfaces, which would theoretically be true for an angle of about 13°. If this were the case, it would readily be understood how the grooved gearing had been used in the dredger under conditions which must inevitably lead to failure.

A saving in coal consumption had been mentioned by Mr. Stoney as having been effected by the change of gear. From a careful examination it had been found that the dredger was now using 17 tons of coal per working week, while the average of the eleven years with the grooved gearing had been 19 tons. The saving therefore of 2 tons per working week, equivalent to 24*s.*, might he thought be fairly credited to the change; and this seemed to be confirmed by Mr. Head's remark about the three-high rolls with grooved frictional gearing, that it took almost as much power to drive the friction pinions as the plate rolls when in action. Making also the very liberal allowance of 2*s.* per week for renewals of straps, brake wheels, and friction rings, instead of the £1 per week previously expended, the alteration of this one detail had resulted in a saving of about £100 per annum, while at the same time, as pointed out by Mr. Stoney, the efficiency of the dredger had been increased about one-sixth or 16 per cent.

The PRESIDENT was sure the Members would wish to offer their best thanks to Mr. Griffith for his valuable paper, showing so clearly what might be used under the circumstances described, and what ought to be avoided.

EXCURSIONS.*

On TUESDAY AFTERNOON, 31st July, after luncheon in Trinity College by invitation of the Local Committee, an Excursion was made in Dublin Bay, in the steamer "Violet" lent by the London and North Western Railway Co., to view the Alexandra Basin, Deep-water Quays, Dredging operations, and Lighthouses of the Port of Dublin, the Baily Lighthouse, and Kingstown, on the invitation of the Local Committee. A description of the Port of Dublin, prepared and presented to the Members for this Excursion by the kindness of Mr. John Purser Griffith, President of the Institution of Civil Engineers of Ireland, Assistant Engineer of the Dublin Port and Docks Board, is reproduced in pages 384–395.

The following Works in Dublin and the neighbourhood were opened to the visit of the Members on the afternoons of both Tuesday and Wednesday, and also on Thursday. Descriptions of these are given in pages 401–414.

Sir Howard Grubb's Optical and Mechanical Works, 57 Rathmines Road.

The Bank of Ireland, Bank-Note Printing Machine; Mr. Henry T. Grubb, Engineer.

The Observatory, Dunsink; Sir Robert S. Ball, F.R.S., Royal Astronomer.

Custom House Flour Mill, Store Street. (Simon's system.)

Messrs. Walter Brown and Co.'s Flour Mill, Hanover Street. (Robinson's system.)

Messrs. William Brown and Son's Flour Mill, Barrow Street. (Robinson's system.)

Messrs. Boland's Flour Mill and Bakery, Ringsend Road and Grand Canal Quay. (Carter's system.)

Mr. John Mooney's Flour Mill, Jones' Road. (Carter's system.)

Messrs. Johnston and Co.'s Bakery, Ball's Bridge.

Messrs. Cantrell and Cochrane's Aerated Water Manufactory, Nassau Place.

Messrs. James Shanks and Co.'s Mineral Water Manufactory, 54 Townsend Street.

Midland Great Western Railway Locomotive Carriage and Wagon Works, Broadstone; Mr. Martin Atock, Locomotive Engineer.

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* The notices appended of the various Works &c. visited in connection with the meeting were kindly supplied for the information of the Members by the respective proprietors or authorities.

Alliance Gas Works, 110 Great Brunswick Street; Mr. W. F. Cotton, Manager.
Dublin United Tramways Works, Inchicore; Mr. William Anderson, Manager.
Messrs. Hill and Sons' Woollen Factory, Lucan.
Messrs. George Shackleton and Sons' Flour Mill, Lucan. (Fiechter's system.)

The Royal Zoological Society's Gardens, Phœnix Park; the Chamber of Commerce, Dame Street; and the Royal Dublin Society's Conversation Room in Leinster House, Kildare Street; were also opened to the Members. A Guide to Dublin and Belfast, specially prepared for the occasion of the Meeting, was presented to the Members by the kindness of Mr. William Anderson, Secretary and Manager of the Dublin United Tramways, by whom they were also invited to a ride through Dublin on tramcars, for enabling them to view the principal portions of the City.

In the evening the Institution Dinner was held in the Royal University of Ireland, Earlsfort Terrace, Dublin, by kind permission of the Senate, and was largely attended by the Members and their friends. The President occupied the chair, and the following Guests accepted the invitations sent to them, though some were unavoidably prevented at the last from being present.

Dublin Reception Committee.—The Right Honourable the Earl of Rosse, Chairman. The Very Rev. Dr. Molloy, Rector of the Catholic University of Ireland; Mr. John P. Griffith, President of the Institution of Civil Engineers of Ireland; Sir Robert S. Ball, Royal Astronomer of Ireland; and Sir Howard Grubb; Vice-Chairmen. Mr. Henry A. Ivatt, and Mr. Samuel Geoghegan, Honorary Secretaries. Mr. W. W. Wilson, Honorary Treasurer. Professor Thomas Alexander; Mr. William Anderson, Manager, Dublin United Tramways; Mr. Martin Atock, Locomotive Engineer, Midland Great Western Railway; Mr. Valentine Ball, Director of the Science and Art Museum; Mr. Kennett Bayley, Engineer-in-Chief, Great Southern and Western Railway; Mr. W. F. Bottomley, Manager, Telephone Co. of Ireland; Mr. Maurice Brooks, D.L.; Sir Charles A. Cameron, M.D.; Sir Henry Cochrane, D.L.; the Right Honourable W. H. F. Cogan, D.L.; Mr. Charles P. Cotton; Mr. William Douglass, Engineer to the Commissioners

of Irish Lights; Professor George F. FitzGerald; Mr. Edward Fottrell, Chairman of the Commissioners of Rathmines and Rathgar; Mr. Charles Geoghegan; Mr. W. Purser Geoghegan; Mr. Robert Goodbody; Mr. Richard A. Gray; Sir John Ball Greene, K.C.B., Commissioner of Valuation and Boundary Surveyor for Ireland; Mr. Henry T. Grubb, Engineer to the Bank of Ireland; Mr. William J. Hall, Harbour Engineer, Limerick; Mr. Spencer Harty, City Engineer; Mr. S. Wilfred Haughton; Mr. John Hodges; Mr. Jonathan Hogg; Mr. William Hogg; Professor Edward Hull, Director of the Geological Survey of Ireland; Mr. T. Maxwell Hutton, D.L.; Mr. G. Newenham Kelly, Chief Engineer, Midland Great Western Railway; Mr. Robert Manning, Engineer-in-Chief, Board of Public Works; Colonel W. D. Marsh, R.E., Commanding Royal Engineers in Ireland; Sir Richard Martin, Bart., D.L., President of the Dublin Chamber of Commerce; Mr. William H. Mills, Engineer-in-Chief, Great Northern Railway of Ireland; Professor J. P. O'Reilly; Mr. W. L. Payne, Traffic Manager, Dublin Wicklow and Wexford Railway; Professor Thomas F. Pigot; Mr. Joseph T. Pim; Mr. James Talbot Power, D.L.; Mr. Thomas Talbot Power; Mr. William Ross; Mr. William Mark Smith; Mr. William Spence; Mr. G. Johnstone Stoney; Mr. William George Strype; Dr. Anthony Traill, F.T.C.D.; Mr. Amos M. Vereker; Mr. William Wakefield, Locomotive Superintendent, Dublin Wicklow and Wexford Railway; Mr. Thomas Walpole; Mr. J. E. Ward, Traffic Manager, Midland Great Western Railway; Mr. Henry Waring; Mr. William Watson, Chairman of the City of Dublin Steam Packet Co.; Mr. W. E. Wilson; and Mr. James Winstanley, High Sheriff of Dublin.

Belfast Reception Committee.—Mr. A. Basil Wilson, Honorary Secretary; Professor Maurice F. FitzGerald; Mr. James C. Park, Locomotive Superintendent, Great Northern Railway of Ireland; and Mr. Joseph Tatlow, General Manager, Belfast and County Down Railway.

The Right Honourable Lord Emly, P.C., Vice-Chancellor of the Royal University of Ireland; the Honourable Charles A. Parsons; Mr. Owen Armstrong, Secretary to the Commissioners of Irish

Lights; Capt. Alexander F. Boxer, R.N., Inspector of Irish Lights; Mr. George Conaty, Manager, Dublin and Lucan Steam Tramway; Mr. William Crawford; Admiral C. B. C. Dent, R.N., Marine Superintendent, London and North Western Railway; Mr. James Dillon; Mr. Patrick J. Donnelly; Mr. Francis A. Doyle; Mr. Frederick P. Fawcett, Secretary to the Rathmines and Rathgar Commissioners; Mr. F. Grayson, Great Northern Railway of Ireland; Mr. Thomas Greer; Dr. Thomas W. Grimshaw, Registrar General for Ireland; Mr. Richard Hassard; Mr. James W. Hill; Mr. George Huxley; Mr. Joseph Ingleby; Major Robert MacEniry, Curator, Royal Irish Academy; Mr. William R. Maguire; Dr. James C. Meredith and Dr. David B. Dunne, Secretaries, Royal University of Ireland; Mr. Robert Meyer; Mr. John Mooney; Mr. Frederic W. Pim; Capt. W. Pirrie, Manager, Belfast Steamship Co.; Mr. George Shackleton; Mr. James Shanks; Rev. John W. Stubbs, D.D., S.F.T.C.D., Bursar of Trinity College; and Mr. John R. Wigham, Honorary Secretary of the Dublin Chamber of Commerce.

The President was supported by the following Officers of the Institution:—Mr. Jeremiah Head, Past-President; Mr. Daniel Adamson, Mr. Charles Cochrane, and Mr. Arthur Paget, Vice-Presidents; Mr. Benjamin A. Dobson, Sir James N. Douglass, and Mr. Edward B. Marten, Members of Council.

After the usual loyal toasts had been proposed by the President, Mr. Cochrane proposed "The Army and Navy and Reserve Forces," which was acknowledged by Admiral C. B. C. Dent, R.N. The toast of "The Dublin and Belfast Reception Committees," proposed by the President, was acknowledged by the Right Honourable the Earl of Rosse. The toast of "Irish Industries," proposed by Sir James N. Douglass, was acknowledged by Sir Howard Grubb. The President proposed the toast of "Our Visitors," which was acknowledged by the Right Honourable Lord Emly. The toast of "The Honorary Secretaries," proposed by Mr. Edward B. Marten, was acknowledged by Mr. Henry A. Ivatt and Mr. A. Basil Wilson. The Rev. Dr. Stubbs proposed the final toast of "The President," by whom it was acknowledged.

On Wednesday Afternoon, 1st August, after luncheon in Trinity College by invitation of the Local Committee, two alternative Excursions were made. By special free tramcars from College Green and special free train from Kingsbridge the Great Southern and Western Railway Locomotive Carriage and Wagon Works at Inchicore were visited (pages 396–398) under the guidance of Mr. Henry A. Ivatt, Locomotive Engineer. By special free brakes provided by the Local Committee the Reservoirs of the Rathmines Water Works in the Glenesmoel Valley were visited under the guidance of the Engineer Mr. Richard Hassard, the Chairman Mr. Edward Fottrell, and the Secretary Mr. Frederick P. Fawcett.

In the evening the Members were invited by the Local Committee to a Conversazione at the Royal Irish Academy, where they were received by the Right Honourable the Earl of Rosse, Chairman, and other members of the Local Committee; by the Rev. Dr. Haughton, S.F.T.C.D., President of the Academy; and by Alderman Michael Kernan, representing the Right Honourable the Lord Mayor of Dublin. They were also entertained by the Lord Mayor in the Mansion House adjoining the Academy.

On Thursday, 2nd August, the Members visited Messrs. John Power and Son's Distillery, John's Lane (pages 398–399), under the guidance of Mr. James Talbot Power and Mr. Thomas Talbot Power; and Messrs. Guinness's Brewery, St. James's Gate (pages 399–401), under the guidance of Mr. Claude Guinness, Mr. W. P. Geoghegan, Mr. Samuel Geoghegan, and Mr. W. W. Wilson.

In the afternoon various others of the Works enumerated in pages 374–375 were visited, the Members proceeding in the evening by special train to Belfast.

An alternative Excursion was made by some of the Members to visit the Bessbrook Spinning Works and the Bessbrook and Newry Electric Railway (pages 415–417), under the guidance of the Chairman Mr. John Grubb Richardson, the Directors Mr. James N. Richardson and Mr. John F. Harris and Mr. Henry Barcroft,

the Engineer Mr. John Hardy, and the Secretary Mr. F. W. Harris. On arrival at Bessbrook they were met by conveyances, and were hospitably entertained by Mr. Richardson at his residence. From the Works they were conveyed by the electric railway to Newry, whence they proceeded in the evening to Belfast.

On Friday, 3rd August, the President and Council and Members were received in the Town Hall, Belfast, by his Worship the Mayor of Belfast, Sir James H. Haslett, Chairman, and other members of the Belfast Local Committee.

The Mayor said it gave him great pleasure to offer in the name of his fellow townsmen and the people of Ulster a hearty welcome to the President and Members of the Institution of Mechanical Engineers in their visit to Belfast, which by labour and industry and perseverance had well earned its title of the northern capital of Ireland. Although the north of the island was to a large extent agricultural, and Belfast itself was surrounded by an agricultural district, yet by the introduction of machinery and the exercise of energy, enterprise, and patience, its people had been able to transform what might otherwise have remained a purely agricultural into a semi-manufacturing district. By the establishment of various industries the difficulties experienced in a district having only one trade had to some extent been obviated, and the enterprise of Belfast had been rendered comparatively independent of the chances and fluctuations attending any single manufacturing industry. The machinery employed in the numerous works which would be visited by the Members, though it might not be of the most varied character, would compare favourably he believed in respect of power and utility with that of other manufacturing districts in the kingdom. It was employed principally in connection with the staple manufacture of linen, and with shipbuilding, which had assumed so important a position in Belfast. These two industries progressed together harmoniously; for, while

(Sir James H. Haslett.)

shipbuilding employed male labour to a large extent, the linen manufacture afforded also in many departments a large amount of employment for female labour. The energy displayed in these two leading industries had ramified into others, with the result that the town and district now possessed a number of smaller manufactures, most of which were progressing successfully, and were thus able to make up to some extent for such depressions as from time to time affected the two larger industries. In explanation of its comparative success in manufacture, the north of Ireland could not lay claim to any natural superiority of climate or soil, in regard to which indeed he believed it was scarcely equal to the south. What was yet to be desired for the country was a still greater influx of mechanical and commercial energy, for rendering both capital and labour more extensively successful, not in the north only, but alike throughout the south, in order that throughout the whole of Ireland the same peace, progress, and prosperity might flourish, which were already met with in her northern capital. During their visit here he trusted the Members of the Institution would have both a pleasant and a profitable time. Whatever competition there might be among the various departments of engineering skill, engineers were all united in the one great object of lightening, by the aid of invention and mechanical ingenuity, the manual labour of mankind in connection with the tasks and necessities of civilisation, and thereby enhancing the value of brain labour, and emphasising the superiority of intellect over brute force.

The PRESIDENT assured the Mayor that the Members of the Institution were delighted to come to Belfast, and to be received with such cordiality by the chief magistrate and principal citizens. The interesting speech in which they had just been welcomed was a sufficient proof that the inhabitants of Belfast had chosen one of their best men to be their Mayor, appreciating as he did the many important problems that touched the welfare of communities and affected the interests of a great city. Many of the Members had visited Belfast before; and, although he himself had not been here for many years, he had always taken great interest in its development

and progress. Remembering that the inhabitants had made the northern capital what it now was by their own hard work and energy, he thought the result spoke volumes for their character and ability. Ranking as the second city in Ireland, Belfast occupied undoubtedly the first place as regarded manufactures, for everywhere was her linen industry appreciated, while her ships were known all over the world. Over the linen industry unfortunately there had been a cloud for some time, he believed; but he trusted it was rapidly dispersing, and that the linen manufacture of Ulster would ere long be more prosperous than ever. There might perhaps have been over-production in past years, and no doubt the trade had been prejudicially affected by other circumstances which had since undergone improvement. The exportation of linen from Belfast to the Continent and America afforded a striking testimony to the stability and the excellent reputation of this important manufacture. In addition to this and to the important industries in connection with her harbour and docks and her large cross-channel trade, Belfast possessed one of the finest industries in the world in her shipbuilding, which was always of the highest interest to engineers, in whatever department they might be engaged. In the Institution of Mechanical Engineers a great many branches of engineering work were represented by the Members, all of whom were proud of their commercial navy and proud of the shipbuilding works which had produced it. And they were especially proud of the Belfast shipbuilding works, because he might say, without detracting from others engaged in the same industry, that these had, in the face of many difficulties, taken the lead in this important branch of engineering. They were therefore looking forwards with pleasure to visiting one of the principal shipbuilding yards in Belfast, where he understood two of the largest ocean-going steamers were at present being constructed for the White Star line. The Members would undoubtedly appreciate fully all they would see in Belfast; they were only sorry they could not make a longer stay. Their best thanks were due to the Mayor, to the Local Committee, and to the Honorary Local Secretaries Mr. A. Basil Wilson and Mr. Bowman Malcolm, for all that had been arranged so completely for their convenience and enjoyment:

(The President.)
before leaving Dublin indeed, advantage had been taken of the last occasion of their being assembled together in that city in their corporate capacity, to pass a formal vote of thanks for the arrangements made for visiting Belfast. The visit and the intercourse which it permitted would be productive, he trusted, of mutual benefit; and whithersoever the Members subsequently went, he felt sure that all would speak well of Belfast and its people.

The Members then visited Messrs. Harland and Wolff's Shipbuilding and Marine-Engine Works, Abercorn Basin (pages 418–419), under the guidance of Sir Edward J. Harland, Bart., Mr. G. W. Wolff, Mr. Walter H. Wilson, and Mr. W. J. Pirrie. The following Works in Belfast were also opened to the visit of the Members during the day; descriptions of these are given in pages 420–430.

York Street Flax Spinning and Weaving Manufactory.
Belfast Ropework Co.'s Rope and Twine Manufactory, Connswater.
Messrs. Marcus Ward and Co.'s Printing and Stationery Works, Dublin Road.
Messrs. Robinson and Cleaver's Linen Warehouse, Donegall Square North.
Messrs. Richardson Sons and Owden's Linen Warehouse, Donegall Square North.
Messrs. Cantrell and Cochrane's Aerated Water Manufactory, Victoria Square.
Messrs. W. A. Ross and Co.'s Aerated Water Manufactory, William Street South.
Messrs. David Allen and Sons' Printing Works, Corporation Street.
Belfast Corporation Gas Works, Ormeau Road; Mr. James Stelfox, Manager.
Messrs. H. and J. Martin's Brick Works, Ormeau Road.
Messrs. Combe Barbour and Combe's Foundry and Engineering Works, Howard Street North.

In the afternoon, after luncheon in the Exhibition Hall at the Royal Botanic Gardens, by invitation of the Belfast Local Committee, an Excursion was made in Belfast Lough in the steamer "Optic," by invitation of the Belfast Steamship Co., to see the Harbour and new Docks and Dredging operations (pages 430–431), and Mew Island Lighthouse by invitation of the Commissioners of Irish Lights (pages 432–436).

In the evening the Members were invited by the Belfast Local Committee to a Conversazione in Queen's College, where they were received by his Worship the Mayor of Belfast, Sir James H. Haslett, Chairman of the Committee, and Lady Haslett.

The Members remaining in Belfast were presented by the Directors of the Belfast and Northern Counties Railway with free passes over that line, for enabling them on Saturday, 4th August, to visit the Giant's Causeway Electric Railway eight miles in length, on the invitation and under the guidance of the Chairman Dr. Anthony Traill, Fellow of Trinity College, Dublin, and the Engineer Mr. William A. Traill, and to see the electric generating station and Dunluce Castle on the way to the Giant's Causeway.

DESCRIPTION OF THE PORT OF DUBLIN.

By Mr. JOHN PURSER GRIFFITH,
President of the Institution of Civil Engineers of Ireland,
Assistant Engineer of the Dublin Port and Docks Board.

Dublin is situated at the head of a bay 6 miles deep and $5\frac{1}{2}$ miles wide, Fig. 1, Plate 74. Large quantities of sand brought in by the sea have accumulated in the bay, forming extensive strands, which are laid dry at low water for a distance of about $2\frac{1}{2}$ miles seaward. The history of Dublin as a port dates back to the year 1707, when the conservancy of the port was vested in the Corporation of the City of Dublin by the Irish Parliament. At that date the combined waters of the Liffey and Dodder flowed across the sands at low water, dividing them into the North Bull and South Bull. From its exposed position the channel thus formed was subject to constant alteration in depth and direction; and this being the only channel by which vessels could reach the city, the early attempts to improve the harbour naturally took the direction of providing a permanent and deep approach to the port. With this view the Great South Wall was constructed during the eighteenth century to shelter the channel from southerly winds, and also to prevent the encroachment of sand. When completed, it accomplished to a great extent the object aimed at by its designers. Portions of the channel up to the city however were still very shallow; and attention was also drawn to a shoal beyond the extremity of the new wall, known as Dublin Bar. This bank stretched from the north side of the bay across the entrance to the harbour in the form of a hook. The deepest water for vessels was round the end of this hook; but across the bank, in a direct line out to sea, there was a depth of only from 5 to 6 feet at low water of spring tides. At the beginning of the present century many eminent engineers and naval officers were consulted respecting

further improvements. Captain Bligh recommended a wall along the north side of the channel; Sir Thomas Hyde Page proposed a similar wall, and the formation of an island on the bar; while a proposal to construct an embankment or wall extending from the north shore towards Poolbeg emanated from the corporation for preserving and improving the port of Dublin, better known as the Ballast Board, to whom the conservancy of the port had been transferred in 1786. Mr. Rennie, at that time considered the highest authority on the improvement of harbours, prepared an elaborate scheme, but he predicted little likelihood of much improvement on the bar. He expected an increased depth of 3 feet of water as the result of an estimated expenditure exceeding £655,000. To provide a better approach, he considered it essential to construct a ship canal from some point on the adjacent coast, where deep water might be obtained, and finally recommended this entrance to be made close to the present site of Kingstown Harbour; his estimate for this work was £489,734. From 1802 to 1819 the question of the improvement of the bar appears to have been in abeyance. Probably Mr. Rennie's scheme, from the large expenditure it would have involved and the smallness of the results anticipated, tended to deter the government from advancing the necessary funds for any particular scheme.

About 1819 the Ballast Board found themselves in a position to carry out their own project of a wall or embankment from the Clontarf shore. Its object was to protect the harbour on the north side from the encroachment of sand, to shelter it from northerly and easterly winds, and to direct the tidal and river waters in a fixed channel across the bar. Before beginning this work however an accurate survey of the river and bar was made by Mr. Francis Giles. Under the joint direction of Mr. Giles and Mr. Halpin the engineer of the Ballast Board, the rubble embankment, now known as the Great North Wall, was constructed, extending about 9,000 feet from the Clontarf shore, its southern end being about 1,000 feet north of Poolbeg Lighthouse. Over 5,500 feet of this wall rose above high-water, the remainder being below that level; and the extreme 2,000 feet reached on the average to half-tide only. During the first half

of the ebb, the tidal and river waters running out of the harbour flow partly over the submerged wall, and partly through the harbour entrance between the termination of the wall and Poolbeg Lighthouse. As soon however as the tide falls below the level of the wall, the water contained within the two great piers of the port passes through the contracted entrance at Poolbeg. The velocity of the stream is thus greatly increased; and a channel has been formed across the bar with 16 feet at low water of spring tides, where in 1819 there was a depth of only 6½ feet. As the improvement of the bar is due to the water discharged from the harbour during the second half of the ebb, any addition to the tidal capacity of the harbour below that level may be expected to produce a corresponding increase in the depth on the bar. Such an increase in the tidal capacity of the harbour is actually taking place by the lowering of the North Strand, the result of dredging and the wasting away of the bank.

A consideration of the difficulties overcome in the improvement of the approach to the port of Dublin naturally leads to the enquiry, what are the dangers which beset the maintenance of the deep-water channel across the bar. These may be briefly summarised as reclamation inside and outside the harbour. Reclamation inside would reduce the tidal capacity on which the scour across the bar depends; while reclamation outside would result in the reduction of the area upon which sand entering the bay is at present deposited, and would tend to drive the low-water mark further out to sea, and greatly endanger the channel across the bar.*

Improvements in the River Channel.—Figs. 2 and 3, Plate 75. The great works which proved so efficacious in increasing the depth of the water on Dublin bar produced no appreciable improvements in the river channel. From the city to within 1,000 feet of Poolbeg lighthouse all improvements in the channel are the result of dredging. Steam dredging was first introduced in 1814; but up to 1860 the total average tonnage raised did not exceed 150,000 tons a year. The introduction of modern dredgers and large hopper-barges gave

* Proceedings of the Institution of Civil Engineers, 1879, vol. lviii, page 104.

a great impetus to dredging operations, and since 1865 upwards of 15,000,000 tons have been raised. The depth of the river channel has been increased from a maximum of 10 feet to 14 feet at low water between Poolbeg and the entrance to the Alexandra Basin; while from the Alexandra Basin to the Custom House the depth has been increased from an average of 5 feet to depths varying from 9 to 24 feet at low water. The site of the Alexandra Basin, which was chiefly tidal strand, has been dredged to a depth of 24 feet at low water over an area of 40 acres.

Most of the dredging has been carried on in connection with the deep-water quay walls of the Alexandra Basin and the North and South Quays. There are still portions of the river channel between Poolbeg and the Pigeon House Harbour where there is a less depth of water than on the bar. The removal of these shoals has unfortunately been delayed by the reduction of dredging operations, necessitated by the diminished revenue of the last few years.

The dredging plant of the port consists of three steam dredgers, three steam hoppers, five towed hoppers, twelve dredge floats, one tug, and three crane floats. At present however only one steam dredger, three towed hoppers, the tug, and six dredge floats are in commission. (See pages 363–373.)

Dublin Quays.—The quay walls along the river Liffey were originally built at very shallow depths; and in 1865, when the Institution of Mechanical Engineers last visited Dublin, the foreshore in front of most of these walls was exposed at low water for many feet outside their base, and vessels lay aground during the greater portion of each tide. To meet the demand for deeper water, timber jetties had been constructed in front of some portions of the old walls, enabling coasting steamers to float at half-tide. The only places in which a vessel drawing 17 feet could lie afloat at all states of tide was in a hole dredged at the east end of the North Wall, known as "Halpin's Pond," about $1\frac{1}{3}$ acres in area; and also at Sir John Rogerson's Quay, alongside a floating stage, where a trench, 250 feet long and 70 feet wide, had been formed.

The following extracts from the harbour master's journal for 1865 and 1866 graphically describe the delay and expense incurred by the want of deep-water berthage at that period. "Ship *Vistula*, of Boston, 1,188 tons register, drawing 22 feet, with a cargo of guano from Peru, bound to Dublin, arrived at Kingstown on the 7th July 1865, where she remained, discharging her cargo into lighters, until the 27th, when she was lightened to 17 feet. She then came to Halpin's Pond, where she had to discharge the remainder of her cargo into lighters, which was not completed until the 28th August." "The ship *Tribune*, of St. John's, N.B., 1,122 tons register, with a cargo of 1,700 tons guano, drawing 22 feet 6 inches, bound to Dublin, arrived at Kingstown on 15th July 1866; detained at Kingstown till 5th August, to lighten to 17 feet, when she came to Halpin's Pond, where, after a delay of thirty days more, she finished her discharge, all by lighters."

Since 1865 timber jetties, 3,516 feet in length, have been constructed outside some of the old quay walls on both sides of the river, so as to allow the berths to be deepened to depths of from 5 to 8 feet at low water. For greater depths these temporary structures were unfitted; and in 1864 the first step was made towards the construction of masonry deep-water quay walls. In 1870 the deepening of the South Quay walls was begun; and since that year 4,047 lineal feet of masonry walls have been built at that side of the river, affording berthage of 22 feet depth at low water for the greater portion of this length. On the North Quay 2,317 feet of masonry walls have been built, affording berthage of 16 feet depth at low water, which is mostly used by cross-channel steamers.

These new walls, which replace old quays, were constructed inside cofferdams, the excavations being carried down till a firm foundation was reached, in some cases at depths of 28 to 32 feet under low water.* The quay walls in Dublin which have attracted most attention amongst engineers are those connected with the

* Proceedings of the Institution of Civil Engineers, 1877, vol. li, page 137. Transactions of the Institution of Civil Engineers of Ireland, 1880, vol. xiii, page 90.

construction of the Alexandra Basin and the North Quay extension. They do not replace old walls, but are extensions to the quayage of the port, intended to provide berthage for the largest ocean-going vessels. Alongside these quays the "Great Eastern" was moored throughout the winter of 1886–87. The North Quay extension quays facing the river afford berthage of 22 feet depth at low water, while the berths along the quays inside the Alexandra Basin have depths of 24 to 26 feet at low water. These walls were constructed up to ordinary low-water level with gigantic blocks of masonry, each block weighing 350 tons, and over the blocks the upper portion of the walls was built by tidal work. The blocks were built on a wharf, and when sufficiently hardened were lifted and conveyed to their destination in the quay wall by a floating sheers. The foundation for the blocks was first excavated by a steam dredger to within 2 feet of the finished level; and the remainder of the excavation was taken out by men working in a large diving-bell, 20 feet square and 6½ feet high. Access was obtained to this chamber by a wrought-iron shaft and air-lock, without lifting the bell. One of the most important features of this mode of construction is the absence of cofferdams, staging, and pumping; and it has proved exceptionally economical, the quay walls having been built for about £40 per lineal foot, inclusive of the cost of all special plant. The whole of the machinery and appliances used in this great work were designed by Mr. Bindon B. Stoney, the Chief Engineer of the Dublin Port and Docks Board.*

The Alexandra Basin is still unfinished; but additional quayage can be rapidly added, when funds are available and further accommodation is needed. The total length of walls built with 350-ton blocks is now 4,911 feet.

Lights, Fog-Signals, Beacons, and Buoys.—The construction of deep-water quays and the improvement of the channel were followed by an increase in the number of passenger steamers entering and leaving the port at fixed hours; and, as this class of traffic developed, the need of improved lights and fog-signals was felt. Previous to

* Proceedings of the Institution of Civil Engineers, 1874, vol. xxxvii, page 332.

1880 there were but three lighthouses in the river: Poolbeg at the end of the Great South Wall; the Perch light on the north side of the channel, nearly opposite the Pigeon House Harbour; and the North Wall light. These were all fixed white lights. The only fog-signals were two small bells at Poolbeg lighthouse. There are now five lighthouses; the old lights have been improved, and fog-signals have been placed at each station.

Poolbeg Lighthouse,* Figs. 3 and 4, Plates 75 and 76, is the oldest lighthouse in the port, having been built in the middle of the last century. In 1880 the old silvered reflectors were replaced by a third-order condensing dioptric apparatus, from which a fixed white light is exhibited. As the light is visible through only a limited arc, advantage is taken to intensify it seaward by condensing prisms and dioptric reflectors. The fog bells have been replaced by a powerful siren sounded by compressed air. The motive power is an Otto gas engine, and the gas is manufactured on the premises. The whole apparatus, including siren, compressor, engine, gas tank, and retorts, is in duplicate. The siren gives two blasts in quick succession every forty seconds in the following order: the first blast is a high note of two seconds' duration, then a silent interval of one second, followed by a low note of two seconds' duration, and a silent interval of thirty-five seconds. As a supply of gas is always ready, the signal can be sounded within two minutes after a fog is noticed. The importance of being able to start fog-signals quickly at the entrance to a port cannot be overrated. The base of Poolbeg lighthouse is protected on the east and south-east by a breakwater of concrete blocks, each weighing 140 tons; these were carried down and laid in place by the large floating sheers.

The North Bull Lighthouse, Figs. 3 and 5, Plates 75 and 76, is a wrought-iron tower on a masonry base founded on the submerged end of the Great North Wall. The lower portion of the masonry consists of two concrete blocks, each weighing 330 tons. These were built on the block wharf in the Alexandra Basin, and carried down and deposited by the floating sheers. The light exhibited is

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* The blocks forming Plates 76 and 77 have been kindly lent by Mr. Griffith.

an occulting white light, bright for ten seconds and eclipsed for four seconds. The optical apparatus consists of a fourth-order dioptric fixed-light apparatus of 360°, with four revolving lenticular screens, which are designed so as to produce the occultations, and at the same time to transfer the intercepted rays to the bright arcs, and thereby intensify the light. In fog a bell weighing 17 cwts. is sounded four times in quick succession every thirty seconds, the hammers being worked by machinery.

The Beacon Lighthouse, Fig. 3, Plate 75, is on the north side of the channel, about $1\frac{1}{3}$ miles inside the entrance of the harbour. It is a brick tower on a concrete base. The light is a fourth-order occulting white light, flashing once every four seconds, the occultation being produced by a cylindrical screen raised and lowered by clockwork. The optical apparatus condenses the light of 270° in azimuth into an arc of 15° to seaward, and the remaining 90° into an arc of 35° up channel. Its great brilliancy to seaward adds to its value as a leading light, in conjunction with Poolbeg and the North Bull, for vessels making for the port. A bell is sounded in fog three times in quick succession every twenty seconds.

The Eastern Breakwater Lighthouse, Fig. 2, Plate 75, is a temporary wooden square tower on the new pier head, from which a small fixed white light is exhibited; and a bell is sounded in fog twice in quick succession every fifteen seconds.

The North Wall Lighthouse, Figs. 2 and 6, Plates 75 and 77, is also a temporary wooden structure at the end of the North Quay extension. The light is a fixed white light, and the optical apparatus a condensing light of the fifth order. A bell is sounded in fog once every ten seconds.

The dioptric apparatus at Poolbeg and the North Wall lights were manufactured by Messrs. Chance Brothers of Birmingham, and those of the North Bull and the Beacon light by Messrs. Barbier and Fenestre of Paris. Messrs. Edmundson and Co. of Dublin erected the gas works, engines, and one siren, at Poolbeg; the duplicate siren, which is on Professor Holmes' plan, was supplied by the Pulsometer Engineering Co. All the fog-bells and their machinery were manufactured by Messrs. Gillett and Co. of Croydon.

The lights and fog-signals of Dublin river compare favourably with those of any other port. In addition to the lighthouses, the north side of the river channel is defined by two concrete towers T and three wooden perches P, Fig. 3, Plate 75, and the south side by iron buoys B painted red.

Graving Dock and Slips.—The port is provided with one large graving dock, two slips, and a gridiron. The dock is 408 feet in length on floor, including the mitre sill; 70 feet in width of entrance; and has a depth on its sill of 18 feet 3 inches at high water of spring tides. Its entrance is closed by a pair of wrought-iron cellular gates, fitted with Mallet's heel and meeting posts. The cast-iron rollers, upon which the gates rolled originally, have been given up; and the upper hinges are now anchored back to the masonry.*

Sheds have been provided at various berths allotted to the principal cross-channel steam-packet companies; and tramways have been laid connecting some of these berths with the railways on the North Wall.

Bridges.—In addition to the works directly connected with the harbour, the Port and Docks Board have lowered and widened Essex Bridge,† now called Grattan Bridge; Carlisle Bridge has been replaced by O'Connell Bridge, Fig. 2, Plate 75, which is the full width of Sackville Street; and a new swivel bridge, known as Butt Bridge, has been built near the Custom House. These works have been paid for out of public rates under the authority of special acts of parliament, and not out of port funds.

Summary of Works.—The following is a summary of the principal works executed in Dublin Harbour since 1865:—

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* Transactions of the Institution of Civil Engineers of Ireland, 1877, vol. xii, page 34.

† Transactions of the Institution of Civil Engineers of Ireland, 1880, vol. xiii, page 32.

Description of Work.	Length. Feet.	Berthage Depth at low water. Feet.
Timber Jetties	3,516	5 to 8
New Quay Walls:—		
Replacing old quays on South Quays	4,047	19 to 22
Replacing old quays on North Quays	3,095	8 to 16
On North Quay Extension, Alexandra Basin, and Eastern Breakwater .	4,911	22 to 26
Sheds	3,377	

Bridges:—Essex (now Grattan Bridge) lowered and widened, 1873.
Carlisle (now O'Connell Bridge) reconstructed and widened.
Butt Swivel Bridge built.
George's Dock Draw Bridge reconstructed.

Lighthouses:—North Bull Lighthouse built.
Beacon Lighthouse built.
Temporary wooden towers at North Wall and Breakwater erected.
Lights improved and Fog Signals erected.

Dredging.—15,000,000 tons.

Port and Docks Board.—The Port of Dublin is under the control of the Port and Docks Board, the successors of the corporation for preserving and improving the port of Dublin. The Board is constituted under the Dublin Port Act of 1867, and consists of 25 members:—the Lord Mayor and three citizens of Dublin appointed by the municipal corporation; seven members elected by the traders and manufacturers; seven members elected by the shipowners; and seven members nominated by the Commissioners of Irish Lights. The principal powers of the Board are defined by the Dublin Port and Docks Acts of 1869 and 1879.

Income.—The income of the port is chiefly derived from dues on shipping and charges on timber, bricks, and marble. In 1887 the former amounted to £49,755, the latter to £1,500. The rates are as follows:—on oversea vessels, $10\frac{1}{4}d.$ per registered ton; on coasting

vessels, $6\frac{1}{2}d.$ per registered ton; on timber, bricks, and blocks of marble, $5\frac{1}{2}d.$ per ton. On the security of the income derived from these rates Parliament has sanctioned borrowing powers for the purposes of the docks and port to the extent of £580,000, and for tramways £25,000.

Tonnage and Revenue.—The following table shows the annual registered tonnage entering the port from 1865 to 1887, and the revenue derived from tonnage rates and dues on timber, bricks, and blocks of marble:—

Year.	Registered Tonnage.	Total Income from Rates and Dues.		
		£	*s.*	*d.*
1865	1,336,754	41,302	7	0
1866	1,363,564	42,363	17	11
1867	1,434,022	44,629	5	10
1868	1,420,292	44,529	3	7
1869	1,513,624	47,834	7	5
1870	1,506,011	47,063	10	6
1871	1,571,602	49,388	7	8
1872	1,649,228	50,894	1	2
1873	1,632,160	49,780	16	0
1874	1,563,847	47,223	3	3
1875	1,677,543	50,844	13	8
1876	1,879,886	57,994	14	5
1877	1,973,781	60,250	18	10
1878	2,026,185	62,417	9	10
1879	1,953,902	59,315	6	5
1880	1,930,277	58,484	18	5
1881	1,816,917	54,617	12	9
1882	1,845,330	56,233	4	11
1883	1,823,214	56,014	18	3
1884	1,773,505	53,736	2	8
1885	1,755,615	54,261	9	1
1886	1,708,146	52,167	10	2
1887	1,672,084	51,255	2	9

It will be noticed that the income of the port reached its maximum in 1878. Since that year there has been an almost continuous decline in tonnage and revenue. Although the tonnage is reduced, there is little doubt that the carrying capacity of the vessels entering the port has not materially diminished, but that the reduction is chiefly due to the construction placed on the law of measurement in 1879 by the High Court of Justice. The Royal Commission on tonnage in their report dated August 1881 say, "We are satisfied that such a construction of the acts is due only to defects in expression, and that it is inconsistent with the principle and intention of the law, as well as with justice and convenience." As Dublin is so largely dependent for its revenue on tonnage rates, the result of this interpretation has been specially injurious to this port, and the loss of revenue has delayed many necessary improvements. The London and North Western Railway Co.'s screw steamer "Anglesey," recently built, illustrates what shipbuilding ingenuity can now do with the view of reducing the registered tonnage of large vessels. This vessel has a gross tonnage of over 800 tons; she is more than 300 feet long, with a beam of 33 feet, and yet registers only 45 tons.

At the end of 1887 there was due £432,500 on mortgage bonds, and £73,476 on Ballast Board debentures, making a total debt of £505,976. If a comparison be made between Dublin and other large ports, it will be found that its income and debt are strikingly small. Since the formation of the Port and Docks Board a sum of £752,478 has been expended on improvements of the harbour, over and above ordinary maintenance, the difference between this sum and the amount borrowed on mortgage bonds having been defrayed by the surplus revenue of the port.

GREAT SOUTHERN AND WESTERN RAILWAY LOCOMOTIVE CARRIAGE AND WAGON WORKS, INCHICORE.

The Works at Inchicore are situated about $1\frac{1}{2}$ miles west from Kingsbridge, the terminal station in Dublin of the Great Southern and Western Railway, and have been in operation since the early part of 1846, previous to the line being opened for traffic on 4th August of that year. They have since been steadily increasing in size, until they now cover an area of fifty-two acres, upon which stand about eight acres of shop buildings. In 1847 the number of men employed was 250; there are now between 1,200 and 1,300. All the rolling stock has for a considerable time been entirely constructed and repaired at these works; and in addition the various articles, such as lamps, barrows &c., required for traffic and other purposes of the railway, are made and kept in repair. The rolling stock consists of 176 engines and tenders, 525 passenger vehicles, and 3,521 wagons.

In Plate 78 is shown a general plan of the works; and the several shops are as follows, taking them in the order in which they come in going round the works from the eastern end.

In the Paint shop all carriages, engines, and tenders are painted, a small gas-engine being used for grinding colours. Connected with this is the Trimming department where the carriages are upholstered.

The Foundry supplies all the iron and brass castings required in the shops, as well as castings for signal and other work for the Permanent Way department. Locomotive cylinders are cast double, and such things as axle-boxes, buffer-sockets, slide-valves, &c., are machine-moulded from standard patterns.

The Locomotive Smithy is 282 feet long and 50 feet wide, and contains thirty-seven fires. As much of the work as possible is done by stamping and welding under the steam-hammer. A large number of standard dies and tools are used for this purpose, the construction and successful use of which are due to the ingenuity of Mr. Owens, the foreman smith. There are three small steam-hammers in the

smithy, which is lighted in the winter time by two steam lucigens; no gas is used. Adjoining is the Forge, containing two Siemens gas furnaces and a 50-cwt. hammer; there are also a rolling mill and machinery for nut and bolt making, spring tester, &c.

In the Boiler shop steel is used for the manufacture of locomotive boilers, and hydraulic riveting is employed as far as possible. Amongst the ordinary boiler-shop tools, there is a multiple drilling machine working six drills, and also a plate-edge planing machine with a horizontal table for doing circular work.

The Sawmill and Joinery contain the usual wood-working machinery. All the scantling required for wagons and carriages is cut here, together with the timber required for bridges, signals, and station works. The sleepers for the permanent way are cut, grooved, and creosoted.

At the Gas Works is made all the gas used in the shops and adjoining houses, and also that required for Kingsbridge terminus. The exhauster is driven by a gas engine.

Coal required for the locomotives is brought by ship to the North Wall, where it is loaded into wagons by the company's hydraulic cranes, and then run to the coal gantry at Inchicore, where it is dropped. The wagons used for this are of iron with drop-bottoms, and carry 10 tons.

In the Carriage and Wagon shop all carriages and wagons are built and repaired. The hydraulic lifting arrangement for carriages is worth notice. Carriage wheels are made on Mansell's pattern, and are all accurately balanced by being run on a pair of springs before they are put into use.

The Smiths' shop adjoining the carriage and wagon shop is 180 feet long by 43 feet wide, and contains twenty-three fires and three small steam-hammers. The system of stamping and welding in dies is carried out as far as possible, such things as wagon hinges being finished direct from the hammer, and requiring no machining in the jaws.

There are two Erecting shops, the western one 326 feet long and 50 feet wide with nineteen pits; the eastern 286 feet long and 50 feet wide with sixteen pits. The shops are provided with rope-

driven gantries, and are divided by a traverser serving all roads in both shops; the traverser is driven by wire rope. On the eastern side of the newest portion of the erecting shop, built in 1883, are the Coppersmiths' shop and Testing room; at right angles to the erecting shops and at their northern end is the Machine and Fitting shop, about 324 feet long by 50 feet wide.

All the stock is built to templates and standard sizes, and great care is taken to have all parts interchangeable.

The Running Shed has eight pits and accommodates forty-eight engines.

Adjoining the works are some 142 cottages occupied by the company's workmen. A dining hall has been provided for the use of those who live at a distance; there are also reading room, billiard room, library, science class-rooms, and dispensary.

The whole of the works are under the control of Mr. H. A. Ivatt, Locomotive Engineer to the company.

JOHN'S LANE DISTILLERY.

This distillery, belonging to Messrs. John Power and Son, is one of the old Dublin distilleries celebrated for the manufacture of "Dublin pot still whiskey," and was established in 1791. The whole has practically been rebuilt and refitted during the past ten years. It covers about eight acres, and reaches from Thomas Street to the quays on the south side of the Liffey. The annual output is about 900,000 gallons; there are from 250 to 300 hands employed, and the daily consumption of coal is from 50 to 60 tons. There are five engines, two of which are McNaught compound beam-engines, one of 400 and the other of about 250 effective H.P., both made by Messrs. Turnbull Grant and Jack of Glasgow. A hydraulic hoist by Messrs. Ross and Walpole of Dublin is worked by the hot-water overflow from the worm tubs; the ram is 22 inches diameter and 29 feet long. The corn screens and mills are of the most approved pattern; and all the elevators are constructed of cast-iron plates so as not to carry or spread fire, and they can be easily opened at any place. The corn stores consist of five floors, and contain

usually 30,000 to 40,000 barrels of grain in the working season, which is from September till June. The mash tuns are 33 feet diameter, and 7½ feet deep, and are capable of mashing at each brewing over 500 barrels. The stills are all pot stills, of which there are six, capable of holding from 15,000 to 25,000 gallons each. There are seventeen distillery bonded warehouses, and two outlying warehouses, one under the market building in George Street, and the other under Westland Row railway station; they are capable of holding in all up to 40,000 casks, having a total capacity of 1,113,000 cubic feet. The stables are built of enamelled brick throughout, and furnished with Musgrave's fittings. The distillery being built on the side of a hill has the advantage of natural gravitation for the movement of the material in process of manufacture.

ST. JAMES'S GATE BREWERY.

This brewery, now the largest in the world, belonging to Messrs. Arthur Guinness Son and Co., was established in 1759, by the purchase of an existing plant from Mr. Rainsford, by Mr. Guinness, an ancestor of Sir Edward Guinness, Bart., the present chairman of the company. As shown in the general plan, Plate 51, it covers about thirty-five acres, exclusive of workmen's dwellings and grounds, and is situated on two levels: on the higher are built the brewhouses, fermenting rooms, and vat houses, the malt and hop stores, stables, and offices; and on the lower are situated the malthouse, the cooperage, and the cask washing and filling sheds, as well as those for delivery of porter and waste products. Only black beer or Dublin stout is brewed, generally in three qualities, —porter, stout, and export stout made especially for consumption abroad. In the manufacture of these the three ingredients used are water, malt, and hops. The first is obtained from County Kildare, and was the city supply until modern requirements demanded a softer water and larger supply and higher pressure; this is supplemented by the present city supply from the Vartry in County Wicklow. The malt is all made from barley, that grown

in Ireland being preferred. There is a malt-house within the brewery limits, but its production of malt is only a small contribution to the whole consumption. The hops are all imported; those grown in Kent have the preference.

There are two breweries: one has been added to from time to time, and is consequently rather irregular in plan; in the other, built in 1877–8 and nearly doubled in 1886, the machinery and plant required in brewing, from the receipt of the malt until the worts are cooled for fermentation, can be seen to best advantage. The malt is received, weighed, ground, and delivered into hoppers preparatory to mashing by machinery. There are in the brewery eight mash tuns, with outside mashing machines, designed in such a manner that four different brewings can be made at the same time. There are four coppers, in which the boiling is done under a pressure of about $1\frac{1}{2}$ lb. per square inch. At the back of this building are machines recently erected for drying the grains in vacuo; the low temperature at which they are thus dried is considered an advantage as adding to the value of this waste product as food for cattle.

A bridge over the yard and running shed leads into the cooling and fermenting houses and thence to some of the cleansing vessels. The greater part of the cooling is done by vertical refrigerators; and the water cooling the hot worts is itself heated and passes back for brewing. As brewing is now carried on in summer much more extensively than in former years, freezing machines have become desirable; the cooling plant, capable of producing from 60 to 70 tons of ice per day, is arranged at the end of the fermenting house; it is used only to cool brine, which is the medium for conveying the cold wherever required. The vats for the storage of the beer cover a considerable area, and are themselves very large examples of cooper's work; some are 26 feet diameter and 26 feet deep.

There is stabling for 150 horses. The last addition made to the brewery is a large malt store, scarcely yet completed in all parts. The malt is stored in octagonal and square bins, $68\frac{1}{2}$ feet deep; when completed the store will be able to receive 2,000 quarters per day, and will store 120,000 quarters. There are also printing offices, and joiners', mechanics', and plumbers' shops on this level.

A short ride by the narrow-gauge railway down through the spiral tunnel (page 329), passing the malt-house, and then down the zigzag, leads to the cooperage and other departments situated on the lower level. All the casks required are made by hand on the premises; and the washing appliances are capable of washing eight thousand casks in a working day of ten hours. The filling of casks is effected by Smith's rackers. The proximity of the lower premises to the railway and the river Liffey offers great facilities for the despatch of such heavy products as porter and grains; and advantage has been taken also of the very large supply of water suitable for refrigerating, which is pumped from a well sunk some 40 feet into the gravel, by engines placed 16 feet below the ground level.

OPTICAL AND MECHANICAL WORKS.

These works, belonging to Sir Howard Grubb, were built about the year 1874, adjacent to the site of the former temporary works erected for the construction of the great Melbourne reflector in 1865. The principal building forms a square of about 70 feet, surrounding a twelve-sided hall of about 42 feet diameter, which was originally constructed for the erection of the Vienna 27-inch refractor, and has since been used as an erecting shop for many instruments of smaller size. Now however a portion of the hall is cut off to form a new polishing room for the 28-inch Greenwich refractor.

In this establishment is conducted every process connected with the manufacture of both the mechanical and optical portions of all kinds of astronomical instruments, except the founding of the metal work and the preparation of the rough discs of glass for the optical portions. The heavier work of turners and fitters is carried on in the lower part of the building; and the light optical and mechanical work in rooms in the upper storey, reached by a gallery round the central hall. The model-makers' workshop, smithy, and room for dividing engines, &c., form separate buildings.

These workshops employ from 35 to 40 hands; and small as they are, they have furnished important instruments to most of

the leading observatories in all parts of the world. At the present time the following instruments are either in process of construction or about to be put in hand:—28-inch refractor for the royal observatory, Greenwich; 8-inch refractor for Venezuela; 36-inch silver and glass mirror for Mr. Crossley's observatory, Halifax; 13-inch standard photographic telescope for the national observatory, Mexico, and also one for each of the three royal observatories at Greenwich, Cape Town, and Melbourne; 13-inch standard photographic telescope, added to 12-inch equatorial for the Savilian observatory, Oxford, and also one added to 8-inch equatorial for Queen's College observatory, Cork; 13-inch standard photographic objective for the royal observatory, Sydney; 9-inch photographic telescope for Sir Henry Thompson's observatory, Hampton; some smaller equatorials for Peking, &c.: 20-foot observatory roof for the royal observatory, Göttingen; 15-foot observatory roof for Venezuela; and 18-foot observatory roof for the national observatory, Mexico.

It is contemplated to make important additions shortly to the buildings and plant, in order to allow of the employment of a larger number of hands to meet the increasing requirements of the work.

BANK-NOTE PRINTING MACHINE AT THE BANK OF IRELAND.

The three operations of inking and wiping the engraved plates and of taking the impression, including laying and removing the paper, are proceeded with simultaneously. The notes are printed from ten engraved plates upon the ten intermediate sides of a horizontal twenty-sided cylinder, kept at the proper temperature by steam inside. The cylinder is held stationary during eight seconds, and is then turned round through one-tenth of a revolution during the next two seconds. During the stationary period, the undermost engraved plate is inked, the uppermost is printed from, and the plate next to be printed from has the wiping of its surface completed by hand. During the motion of the cylinder, a wiping roller presses against the surface of the previously inked plate, and wipes

off the greater portion of the superfluous ink. There are two attendants, one of whom lays the paper and removes it after being printed, and the other gives the final wiping to the surface of each plate. During each printing the cylinder is locked by a steel tooth inserted into one of ten spaces round its circumference. The cylinder is turned between each printing by means of two levers actuated by cams; one lever inserts a tooth into one of the spaces round the cylinder as the locking tooth is withdrawn, and by the other the box carrying the tooth is moved through the required arc.

The motion of the printing roller is produced by two sets of cams, one of which, acting through a rod and bell-crank and toggle joint, produces the vertical descending movement, and the other traverses the roller horizontally over the engraved plate with a parallel motion; the return movement of the roller is effected by the joint action of the two sets of cams. The bearing surfaces are kept in contact by spiral springs, and the pressure on the roller is about 3 tons.

The inking roller, formed of a number of woollen discs screwed up tightly upon a spindle and finished in a lathe, is worked to and fro without intermission by a rack and sector. The roller is held up to the engraved plate by an adjustable weighted lever, and when the pressure of the weight is removed by a cam the roller drops upon the inking table. The ink is forced up out of a cylinder, through a perforated flat plate of steel forming the inking table, by means of a piston having a screwed piston-rod. The thickened ink is removed from the surface of the inking table once in every thirty-six impressions by a scraper worked by a cam and ratchet.

The designs forming the bank-note are first engraved by hand on separate steel blocks, which are afterwards hardened and preserved as permanent patterns. The engravings are then transferred in relief to the surfaces of soft steel rollers, by rolling these over the pattern blocks under a heavy pressure; and the rollers after being hardened are used as dies to impress the engraving upon the printing plates of soft steel. These plates are easily repaired by applying the rollers to them again; and the table on which the plate is laid for receiving the pressure of the master roller can be slightly

tilted so as to bring up the impression on any particular portion. The bed of the table is made with a convex cylindrical segment lying within a concave one, the plate to be engraved being in the centre of motion. A complete description of this bank-note printing machine, which was constructed by the late Mr. Thomas Grubb, was given by him in a paper read at the former Dublin Meeting of the Institution (Proceedings 1865, page 166).

THE OBSERVATORY, DUNSINK.

The astronomical observatory of Dunsink, belonging to Trinity College, from which it is five miles distant, is situated on an elevated and beautiful site to the north of the Phœnix Park. It contains a large meridian circle by Pistor and Martin; a 12-inch refractor mounted by Grubb, with an object glass by Cauchoix; and a recording chronograph.

CUSTOM HOUSE FLOUR MILL.

This mill, the property of Messrs. MacMullen Shaw and Co., was worked with fourteen pairs of stones until March 1886, when it was fitted by Mr. Henry Simon of Manchester with a complete roller plant, capable of working up to eight sacks of flour an hour. The machinery is driven by two horizontal condensing engines, with cylinders 21 inches diameter and 4 feet stroke, together indicating 130 horse power; the valves are double-beat, and are caused to revolve slightly at each lift, so that they fall on a new face each time. Steam is supplied from two Lancashire boilers, each 30 feet long and 6 feet diameter. The wheat-cleaning department occupies the three floors over the engine-house, and contains a zigzag separator, two of Byrne's vertical scourers, a Young's double aspirator, a Throop's brush machine, a magnetic machine, and a rotary sieve; the last serves to grade the wheat into two sizes before going to the first break roller.

On the ground floor of the mill proper is the main driving spur-wheel, of about 8 feet diameter with helical teeth, fixed on the engine

shaft and gearing into a pinion of 3 feet 8 inches diameter upon the main shaft, which carries a rope drum of 8 feet diameter having grooves for eight $1\frac{1}{2}$-inch ropes. Four of these ropes drive a lay-shaft, from which the roller mills on the first floor are put in motion; and the other four drive the shafting on the second floor, from which power is transmitted to the remaining machinery. On the ground floor are the bottoms of seventeen elevators.

On the first floor are nine sets of Simon's roller mills for the reduction of the wheat and the flouring of the middlings. The wheat is reduced in six breaks, of which the first is effected in a four-roller mill with grooved chilled-iron rolls; the two sizes of wheat, as they come from the cleaning department, are here reduced separately on opposite sides of the machine. The five remaining breaks are effected in three similar mills with rolls of 10 inches diameter. The flouring of the middlings, and the reduction of the semolina, are performed by five three-high smooth-roller mills, four of which have rolls of 10 inches diameter; and there is also a four-roller mill with 7-inch rolls. Underneath this floor is the exhaust trunk, 12 inches square, through which by means of a suction fan the heated air is drawn from the spouts connected with the roller mills.

The dressing machinery is arranged on the second and third floors. On the second floor is a double gravity purifier, and a single gravity purifier for the semolina, both of which are fitted with adjustable valves, and effect thirty-six separations; a double reform purifier and a sieve purifier which are fed with the tailings from the centrifugals; a sieve purifier for the break middlings; a silk reel, 22 feet long, receiving its feed from a similar reel on the floor above, and dressing the break meal from the second and third and fourth breaks; a dust collector exhausting from the two sieve purifiers and from the roller mills on the first floor; also the worm conveyors which collect the flour from each machine. The spouts are so arranged that the working of the mill can be checked by an examination of each distinct flour as it falls from the centrifugals, before it is mixed in the conveyors.

On the third floor is a silk reel, 22 feet long; eight three-sheet centrifugals with double worm conveyors; a first-break scalper,

which is a combined wire and silk centrifugal; three purifiers built in one frame and provided with a grading sieve; a silk reel, 19 feet long, for offals; and a purifier for the coarse branny middlings before their reduction in the smooth-roller mill on the first floor; also scalpers; and nineteen elevator tops, arranged all in one line, and each driven separately. One of the centrifugals is of the double horizontal kind, treating two distinct products, one at each end. The head sheet of the first-break scalper is covered with wire to scalp the first-break product, and the remaining part with silk to separate the dirty flour and middlings. The purifiers are used for the preliminary purification of the first quality of semolina, which passes thence to the larger semolina purifiers on the floor below.

The warehouse adjoining the mill has three floors, and is capable of holding 6,000 barrels of wheat, each barrel containing 280 lbs. It is divided into two distinct portions, and in each half are two sets of elevators. One set carries the wheat from the ground-floor entrance to the storing floor above, and the other set carries it into the wheat-cleaning department.

HANOVER STREET FLOUR MILL.

This establishment, belonging to Messrs. Walter Brown and Co., was originally an oil mill, but in 1862 the building was raised two floors higher and fitted up for the manufacture of flour. It was worked at first with stones, then with stones and rollers combined, and finally in 1885 was fitted by Messrs. Thomas Robinson and Son of Rochdale with a complete roller plant capable of working up to eight sacks of flour an hour. The old condensing beam-engine, which had run night and day almost continuously for nearly twenty-four years, was replaced in 1886 by a horizontal compound twin condensing engine, designed by Mr. A. B. Wilson, and built by Messrs. Victor Coates and Co., Belfast. Steam at 100 lbs. pressure is supplied from a large multitubular boiler of the marine kind, constructed by Messrs. Harland and Wolff, Belfast. On the first floor of the mill are two Garden City first-break discs, the break rolls, and two tailing rolls in one line; and all the smooth

rolls in another. The first break, after grading the wheat, is done on the discs, and the other six breaks are made on the rolls. In 1869 a new chimney stack and a large new granary with four lofts were built.

DOCK FLOUR MILL.

This mill, belonging to Messrs. William Brown and Son, was one of the first in Dublin to use steam power, middlings purifiers, porcelain rolls, and American bolting reels; and when roller milling first came into notice, it contained twenty pairs of stones. Subsequently a half high-grinding system was introduced with smooth iron and porcelain rolls. In 1885 the mill having been destroyed by fire was immediately rebuilt and fitted, by Messrs. Thomas Robinson and Son of Rochdale, with a full roller system capable of working up to eight sacks of flour an hour. The new mill is 63 feet by 35 feet inside, and contains four floors and a basement. In the basement are the shafting and pulleys, receiving motion from the fly-wheel of the engine; and the bottoms of twenty-three sets of elevators. On the ground floor are twelve double horizontal roller mills: four are used for the breaks, which are seven in number; and eight for the reduction of middlings and semolina. The first break is performed on a three-roll machine, the centre roll being fixed and the two outer rolls working against it; the corrugations are two to the inch, and the centre roll has smooth and corrugated surfaces for breaking hard and soft wheat respectively. The second and third breaks are performed by rolls 9 inches diameter and 24 inches long; and the remaining four breaks by rolls 9 inches diameter and 30 inches long. The roller mills are all exhausted by means of a powerful fan on this floor. The first floor contains three purifiers for re-purifying middlings, a wheat grader and weigher, two flour packers, and three offal packers. On the second floor are the clean-wheat bin, a gravity purifier, three sieve purifiers, a dusting centrifugal, four flour-dressing centrifugals, and two reels for re-dressing the flour. The third floor contains the remainder of the dressing machines, namely two reels for germ meal and for grading, eight centrifugals

for flour dressing, a shorts duster and a bran duster, and six break scalpers, in which are incorporated the re-scalpers. The wheat is wormed in on this floor from the adjoining screen room. The attic contains a sorting reel and the elevator heads. The screen room or wheat-cleaning department is separated from the mill proper, and contains separators, Morgan scourers, eleven cylinders for separating oats and barley, one of Herbert and Law's Waverley scourers, a Garden City brush machine, a magnetic separator, a large dust collector for collecting the dust from all these machines, and Howarth's dust collector for collecting dust from the rolls. The motive power is supplied from a vertical compound condensing engine with cylinders 17 and 29 inches diameter and 3 feet stroke, fitted with automatic cut-off. The engines and boilers were supplied by Messrs. Rowan of Belfast.

RINGSEND ROAD FLOUR MILL, AND CITY OF DUBLIN BAKERY.

The flour mill belonging to Messrs. Boland, situated at the edge of the Ringsend Dock, was worked with more than forty pairs of stones until 1880, when eighteen pairs were replaced by Mr. J. Harrison Carter of London with a complete roller plant capable of turning out 200 sacks of flour per day of twenty-four hours; and twenty-two pairs of stones are still used, which can produce about 150 sacks of flour per day. The warehouse is a stone building of seven storeys, capable of holding 3,000 tons of wheat, and having its floors supported on iron columns. It contains a warehouse separator and a cockle machine for the preliminary cleaning of the grain, and a Simon's automatic weighing machine. The grain is lifted by means of large elevators, and distributed by belts to the various hoppers containing the several grades of wheat. In the cleaning department the wheat passes through a Victor smutter, two Seck polishers, and two Throop brush machines.

In the Roller mill department, the basement is occupied by the shafting and pulleys for driving the machinery. On the ground floor, ranged in three rows, are the roller mills for reducing the

wheat into flour in six breaks. The first break is effected on two of Fir's mills with grooved chilled-iron rolls, and the remaining five breaks are performed on five similar mills by Messrs. Escher Wyss and Co. The flouring of the semolina and middlings is effected by nine of Carter's three-high mills with smooth chilled-iron rolls, and four of Wegmann's porcelain roller mills. On the first floor are six scalpers for separating the broken particles of the wheat from the semolina middlings and flour, a hopper holding the wheat for the first break, and a packer for packing the bakers' flour. On the second floor is one of Penney's wheat graders for sizing the wheat before it is fed into the hopper of the first-break roller mill, two of Carter's three-high smooth-roller mills, a bran duster, a centrifugal for the low grade, and one of Mooney's dust collectors exhausting the heated air from the roller mills on the ground floor; also a worm table consisting of a number of worms placed close together longitudinally, for facilitating the examination of the various products which can be transferred from the different machines to any one worm on the table. On the third floor are two of Carter's gravity purifiers, two of Smith's purifiers, one double-sieve Garden City purifier, one Hunter purifier, and a dust collector which collects the stive from the Garden City purifier. The fourth floor contains eight centrifugals covered with silk, two covered with wire, a dust collector, and the cleaned-wheat hopper. On the fifth floor are eight centrifugals, two long silk reels for grading the semolina, and three fans, one exhausting from the dust collector, one from the roller mills, and one from the gravity purifiers. The machinery is driven by two twin horizontal surface-condensing engines, having cylinders 20 inches diameter and 46 inches stroke, with a fly-wheel 15 feet diameter. They indicate 180 horse-power, and were built by Messrs. Fairbairn about twenty years ago. The steam is supplied at a pressure of 60 lbs. per square inch from a steel tubular boiler of the marine kind, 18 feet long and 10 feet diameter, containing 140 tubes and three furnaces, and made by Messrs. Bewley Webb and Co. of Dublin.

In the Stone mill department, the basement is occupied by shafting and pulleys and two fans exhausting from a dust collector

on the first floor, which also contains twenty-two pairs of millstones. On the second floor is a large break machine, four sets of smooth chilled-iron roller mills, a long dusting reel, the hoppers for feeding the millstones, and a dust collector. The third floor contains a scalper, two centrifugals, and five purifiers. On the fourth floor are six silk reels, 24 feet long, and a purifier. The fifth or top floor is devoted to the remainder of the dressing machinery, consisting of six silk reels, a centrifugal, a purifier, a bran duster, and a dust collector. The power is obtained from a beam-engine of 100 indicated horse-power, with cylinder 30 inches diameter and 6 feet stroke and a fly-wheel 28 feet diameter; the engine was erected in 1846 by Messrs. Fairbairn, and drives the mill through gearing bolted to the fly-wheel. The steam is supplied by two Lancashire boilers, 36 feet long and 6½ feet diameter, constructed by Messrs. Barrington of Dublin.

The City of Dublin Bakery, erected in 1874, occupies an area of 15,000 square feet, and stands in its own ground of 3½ acres. The main bakehouse measures 100 feet by 120 feet, and its roof consists of a double arch supported by iron spans and cast-iron columns. It contains two rows of ovens, ten in each row, heated by coal and fired from the side. The kneading is performed by seven machines, in each of which about two sacks of flour is stirred and kneaded by means of a couple of blades working on a horizontal axis, and set at such angles as to ensure the most thorough treatment of the mass. The kneading troughs are fed from an overhead gangway, along which the materials are run on a tramway. Parallel with the kneaders is a line of moulding boards, on which the dough is shaped into loaves ready for baking; these boards are served by 100 troughs running on wheels. All the operations are timed with great precision by signals from the foreman. In a smaller bakery are four ovens; and a bakehouse for fancy-bread is provided with four of Perkins' steam ovens heated by superheated steam in iron pipes arranged in two horizontal layers, the upper layer forming the crown of the oven, while the lower passes underneath the iron plate flooring. In front of these ovens are hot plates for giving the dough a preliminary baking.

BALL'S BRIDGE BAKERY.

This bakery, belonging to Messrs. Johnston and Co., has recently been completely re-modelled on the most modern system; and has been fitted with Pfleiderer's improved dough-making machinery, the necessary baking facilities being afforded by twenty-five of Bailey and Baker's continuous ovens. Water power is employed for driving the machinery. The establishment is capable of baking 1,000 sacks of flour per week. About 150 men are engaged in the work of the bakery, and over 50 horses and vans.

AERATED WATER MANUFACTORY.

These works, belonging to Messrs. Cantrell and Cochrane, are situated in Nassau Place, and cover nearly half an acre. They employ over 500 men, and if required can turn out 160,000 bottles per day, tramways being laid down in all directions to facilitate the conveyance of bottles in the works. The water is obtained from the famous St. Patrick's well. There are two large generators of carbonic acid gas, two powerful steam engines, a travelling lift designed by Sir Henry Cochrane, and twelve bottling machines, of which four are automatic rotary machines and are each capable of turning out 2,000 filled bottles per hour, requiring five boys to tie them. The gas from the generators, after being thoroughly purified, is stored in gasometers to be drawn off as required; and a pressure of about 150 lbs. per square inch is employed for impregnating the water with it. In the cleaning department the bottles are first placed in hot water, then brushed both inside and outside, and finally rinsed in pure cold water. They are then passed to the bottling machines ranged down the centre of the bottling room, and are placed beneath the mouth of the feeding-tube; the cork is driven nearly home by a descending rod, and the required quantity of flavouring syrup is then forced in, the atmospheric air exhausted, the bottle filled up, and the cork driven home and wired. The automatic rotary machines are each fed by one man, and perform all the above operations automatically, except the wiring. In order to avoid risk of metallic contamination,

nothing but gutta-percha, glass, and silver is used in connection with the bottling machines; and glass, porcelain, or similar material in the syrup department, which is situated above the bottling room. The bottles to be shipped abroad are packed in barrels, being surrounded by hay and straw to prevent risk of breakage.

MINERAL WATER MANUFACTORY.

This factory, the property of Messrs. James Shanks and Co., was established in 1868, and occupies the site formerly covered by the famous Dublin Ale Brewery of Messrs. Alley. Some of the old brewery buildings are still in existence, in sound condition, and form part of the present concern; but the main building is new and contains three storeys. The ground floor is laid in concrete, and the upper floors are formed of planks supported on iron girders and metal columns; the roof is mainly of glass. The motive power is supplied by an Otto gas engine, and the machinery is of the most improved kind from a number of makers. Some of the carbonic acid gas generators, pumps, and condensers, are by Mondollot of Paris; and there are also some of the Belfast pattern. Both hand and power bottling machines are employed, and are fitted with perforated guards to obviate risk from the explosion of bottles. Wire eye-protectors are also worn by the operatives at work close to the filling machinery. The factory is spacious, well lighted, and airy, and work is carried on under the best conditions. The aerated beverages manufactured find markets in North and South America and the colonies, as well as in Dublin and the south and west of Ireland.

MIDLAND GREAT WESTERN RAILWAY LOCOMOTIVE CARRIAGE AND WAGON WORKS, BROADSTONE.

The principal feature of these works is the engine building and repairing shop, erected about nine years ago. It is 217 feet long by 200 feet wide, under one roof consisting of six bays; and is fitted with all the necessary modern machinery and appliances. Engines and tenders are lifted by hydraulic travelling gantries. The

machinery is driven by a combined pair of compound non-condensing wall engines of 120 nominal H.P. The boiler-makers' and smiths shops are furnished with Tweddell's hydraulic riveting machines and other labour-saving tools, steam hammer, and shingling furnace. The carriage and wagon shops, where building and repairs are done, are supplied with all needful wood-working machinery, that in the carriage department being driven by an Otto gas engine.

ALLIANCE GAS WORKS.

The works of the Alliance and Dublin Consumers Gas Company consist of four stations, two of which occupy $6\frac{1}{4}$ acres in Great Brunswick Street, Dublin, and one is at Kingstown and one at Bray. The district for lighting extends from Clontarf on the north side of the river Liffey to Bray Head, a distance of 12 miles down the coast, and comprises an area of 98 square miles. The number of miles of mains of various sizes from 3 feet to 3 inches diameter is about 620. Between 120,000 and 130,000 tons of coal and cannel are carbonised yearly, producing from 1,300 to 1,400 million cubic feet of gas. The coal is brought by steamer from Newcastle, and discharged by means of steam cranes into iron trap-bottom wagons, which are either sent direct to the retort houses and emptied in front of the retorts, or to a steam lift at the end of the coal store, through the roof of which runs a line of rails, with a friction lowering cage at the end for empty wagons only. The retort houses are five in number, two being on the stage principle; they contain altogether 1,550 retorts, and are capable of producing over 7,000,000 cubic feet of gas per day, which is more than a million cubic feet beyond the present requirements. The firing is direct, with either coke or tar. The materials used in the purifiers are oxide of iron or bog ore from King's County, and lime.

DUBLIN UNITED TRAMWAYS WORKS.

At the car works and depot, situated at the terminus of the line at Inchicore, can be seen the processes of tramcar building and the

stables. At Kingsbridge, adjacent to Guinness's Brewery, is a granary and depot, where forage for over 1,000 horses is prepared and sent out daily; there are also stables here. At Terenure there is a depot for 200 horses; and at Rathfarnham Road, Terenure, another for 108 horses.

LUCAN WOOLLEN FACTORY.

This factory, belonging to Messrs. Hill and Sons, and situated at Lucan about six miles west of Dublin, was founded in 1869 for the manufacture of Irish wool chiefly grown in the neighbourhood. Commencing with one dozen looms it now employs about 300 hands. The entire process can be seen from the taking in of the wool to the turning out of the cloth. The machinery is driven by water power by two turbines and one ordinary water-wheel; and a steam engine is now being added for driving more machinery that has lately been erected. The mills are lighted by electricity, the generators being driven by a turbine. The durable cloth manufactured is disposed of largely in Ireland, and a considerable quantity is now finding favour in England and America.

ANNA LIFFEY FLOUR MILL, LUCAN.

These mills, belonging to Messrs. George Shackleton and Sons, are situated on the river Liffey near the village of Lucan, about six miles west of Dublin. They have been enlarged several times since 1860, and were worked with twelve pairs of stones until 1884, when they were re-fitted by Messrs. John Fiechter and Sons of Liverpool with a complete roller plant capable of working up to about 1,000 sacks of flour per week. Power is obtained from the river, by means of a breast ventilating-bucket wheel of 70 horse-power, and an inward-flow turbine of 50 horse-power, supplemented in the summer months by a compound semi-fixed engine of 25 horse-power.

BESSBROOK SPINNING MILLS AND ELECTRIC TRAMWAY.

The Bessbrook Flax Spinning Mills, which are amongst the oldest in Ireland where power spinning has been carried on, owe their existence to a stream of the same name, which furnished power before the age of steam. Their situation is shown in the plan, Plate 79. In 1846 they came into the possession of Mr. John Grubb Richardson and his brothers, who erected the present buildings chiefly of cut granite, which is the prevailing stone of the district; since that time additions have frequently been made of the same substantial material. The manufactures carried on in addition to flax spinning are the bleaching of yarns and the weaving of various classes of linen fabrics, including damasks, towels, and sheetings. The weaving of double damask table-cloths, of better quality and without right and wrong side, was first accomplished here in 1868 in jacquard machines modified for the purpose by Mr. Barcroft. In one of these looms was woven in 1876 a double damask table-cloth representing a group three-quarters life-size from Benjamin West's picture of Penn's treaty with the Indians; the production of the pattern required 17,000 cards with 1,530,000 holes and blanks, instead of the 255,000 cards with 102,000,000 holes and blanks which would have been necessary in the ordinary jacquard loom. The principal works are driven by three pairs of steam engines and a turbine; the engines are a horizontal tandem of 450 HP., a reconstructed compound of 450 HP. with large jacketed receiver, and a pair of beam-engines of 600 HP.; the turbine, of 160 HP. with 48 feet fall of water, is situated underground and geared to the engines. Several smaller turbines and steam engines are also kept at work for various purposes.

In 1870 extensive waterworks were constructed for supplying the town of Newry as well as the mills. Five miles of catchment drains were laid, and storage was provided for 750 million gallons by the construction of a reservoir known as Camlough Lake, which is situated about two miles from Bessbrook in a mountain valley.

The various works of the Bessbrook company give employment to rather over 3,500 hands, and a number more are engaged in handloom manufacture, which is carried on in cottages over a considerable area in Ulster. The village of Bessbrook, which has been built from time to time by the firm, has now grown to the proportions of an Irish country town, having a population of about 3,500. The district around being thickly populated, many of the workers come from some little distance. A spacious hall has recently been erected, with library and reading rooms &c. From the Bessbrook granite quarries and polishing works, which are about a mile distant, some very fine work has been supplied, including one of the spiral staircases in the Manchester Town Hall.

In order to connect Bessbrook with the Great Northern Railway and also with the port of Newry, an electric railway of 3 feet gauge and 3·03 miles' length was opened about three years ago,* for which the electrical plant was designed by Dr. Edward Hopkinson. The motive power is generated exclusively by water power, at Millvale, half way to Newry, Plate 79. The turbine here erected for driving the dynamos is an inward-flow vortex-wheel with double buckets, working on a horizontal shaft from which the two Edison-Hopkinson dynamos are driven direct through belts. It is worked by a total fall of water of 29½ feet, of which 16½ feet is pressure in the head pipe and 13 feet is suction in the tail pipe. When running at 290 revolutions and 1,504 cubic feet of water per minute it develops a maximum of 62 HP. The working potential of the dynamos is 245 volts with an average current of 72 ampères, when driven at 1,000 revolutions per minute; and one dynamo is sufficient for the working of the traffic. The line rises from Newry to Bessbrook almost all the way; the total rise amounts to 185 feet, or 1 in 86 on the average, the steepest gradient being 1 in 50. A maximum load of thirty tons, including vehicles and passengers, is drawn up the three miles in thirty minutes by one dynamo. A novel feature of this railway is the employment of wagons having wheels

* Proceedings of the Institution of Civil Engineers, 1887, vol. xci, page 193.

with plain tires, without flanges, so that they are used also on the ordinary roads at either end of the line, thereby avoiding transhipment of goods. Immediately outside the rails of 3 feet gauge, on which the electric cars run, are laid on each side smaller rails 7–8ths inch lower; on these run the flangeless wagon wheels, being kept in position by the higher rails, which act as guard rails. To suit the ordinary roads, the wagon wheels are also loose on their axles, while these are not fixed but run in journals; there is thus freedom in both wheel and axle, whereby the friction is considerably reduced, especially in running round curves. Twenty trains are run daily, ten in each direction, making a mileage of 60 miles a day. Since the opening of the line in October 1885 up to 31 July 1888 it has carried 244,000 passengers and 34,501 tons of merchandise with a mileage of 53,940 miles. During July 1888 the traffic was 6,846 passengers, and 1,590 tons of goods, and 1,668 miles run; the daily averages were 240 passengers and 61·3 tons. In 1886 the traffic amounted to 97,668 passengers and 12,000 tons of merchandise.

At Millvale the line crosses the county road obliquely on the level for a distance of fifty yards. The central rail forming the conductor throughout the rest of the line is here replaced by overhead wires on the method devised by Dr. John Hopkinson. The gates protecting the crossing are opened and shut automatically by water-power, which is thrown in and out of action by the passing car striking a lever before reaching the gates and again after having passed through them.

Near the middle of its length the line passes under the Craigmore viaduct of the Great Northern Railway, having eighteen arches and a height of 126 feet from the stream to the rails.

SHIPBUILDING AND MARINE-ENGINE WORKS, BELFAST.

These works, situated on Queen's Island and belonging to Messrs. Harland and Wolff, were originally started in 1853 by Messrs. Robert Hickson and Co., in order to use the product of the Belfast Iron Works which had been commenced in 1850; but owing to the cost of importing coal the iron manufacture had to be given up in a few years. In 1854 was launched a sailing ship of 1,289 tons. In 1859 the iron shipbuilding yard of Messrs. Hickson and an adjoining wood shipbuilding yard were acquired by Mr. Edward J. Harland, who was shortly afterwards joined by Mr. G. W. Wolff and later by Mr. Walter H. Wilson and Mr. W. J. Pirrie. The progress from 1859 was very rapid: in the five years ending with 1864 thirty vessels measuring 30,276 tons were constructed; in the five years 1865–69 thirty-six vessels and 28,023 tons; in 1870–74 seventeen vessels and 46,283 tons; in 1875–79 forty-four vessels and 57,068 tons; in 1880–84 forty-two vessels and 105,626 tons; and in the three and a half years ending June 1888 thirty-four vessels and 89,769 tons. There are also at the present time eight vessels in different stages, amounting to about 41,330 tons, all being constructed of steel. In 1868 the gross tonnage included H.M. screw gun-vessel "Lynx"; in 1878 H.M.S. "Hecla," a torpedo ship; in 1880 H.M. screw gun-vessel "Algerine"; and in 1886 H.M. screw gun-vessels "Lizard" and "Bramble." In 1870 was launched the "Oceanic," the first of the famous "White Star" fleet, which may be said to have marked a new era in the history of Atlantic steam navigation. Since this date have been constructed for the same line no less than twenty vessels with a tonnage of 75,000; and there are now in hand four vessels of 28,950 tons. In 1858 the business commenced with a staff of a hundred men and a yard of about $1\frac{3}{4}$ acres in extent. The concern now covers upwards of 40 acres, employs above five thousand hands, and expends in wages alone over £300,000 annually.

As shown in the general plan, Plate 80, the works are excellently situated, the building slips being at each end, with a depth of water

sufficient for launching the largest vessels for mercantile or war purposes. Between the two ranges of slips are situated the workshops, which consist of extensive smiths', fitters', and platers' shops, fitted up with the necessary machinery; painting shops; sail lofts; riggers', mast building, and boat building shops; joiners', cabinet-makers', upholsterers', carvers', and polishers' shops; and plumbers' and coppersmiths' shops: the whole arranged with a view to the greatest economy of labour. A narrow-gauge tramway intersects the entire works and connects the various departments. There are extensive piles of timber, iron, steel, and other materials, and locomotive cranes for handling them.

Passing through the ship yard, and crossing the slip and part of the graving dock, and the fitting-up jetties, and thence across the caisson, the engineering portion of the establishment is reached, forming the southernmost portion of the premises. Alongside is Abercorn Basin, where the largest ships are easily accommodated for receiving their machinery. Lines of rails intersect the shops, and run under the eighty-ton steam-sheers on the quay. The buildings are reared on massive iron columns supporting iron girders, which in turn carry the powerful steam travelling cranes in each bay. In the principal building the centre space is reserved for the erection of the engines under construction, and the remainder of the building is fitted with machines and tools of the most modern type. Another block of buildings comprises the boiler house, containing three large boilers which provide steam for the entire works; also the general store, the brass foundry, and the coppersmiths' shop. Next is the iron foundry with cupolas and all other appurtenances for the production of the heaviest castings. Beyond is the boiler shop with appropriate machinery. The mechanical appliances are all of the most approved kind, and many of novel construction, enabling the largest engines to be turned out for meeting the steamship requirements of the present day. The works are lighted by electricity, and all the departments are connected by telephone with the main office and with one another.

YORK STREET
FLAX SPINNING AND WEAVING MANUFACTORY.

These works were founded in 1830 by the late Mr. Andrew Mulholland, and are believed to be the first of the kind in Ireland. They occupy a space of 786 feet by 221 feet or an area of four acres, extending from York Street on the east to North Queen Street on the west, and from Henry Street on the south to Sussex Street on the north. They employ about 4,000 workers.

The central part of the west end, a fire-proof building of eight flats, with an intermediate stage between the first and second, occupies a space of 124 feet by 50 feet; it contains the stairs, lobbies, and cage hoists, which also serve the wings: also covered loading and receiving chambers, and a tackle hoist at the north end. In it are stored the flax, tow, dressed line, brown cloth, &c. The roof forms a cistern supplying hydrants on the lobbies.

The south wing is a building 72 feet by 40 feet, and has five flats. The upper floors are formed of 4-inch planks, bolted to wrought-iron beams, and having hoop-iron slips in the joints, and covered with $\frac{5}{8}$-inch Baltic flooring. The outer edges of the flooring rest on the set-off of the walls, or else the brickwork is corbelled over to receive them, so as to prevent dust from falling through, or water in case of fire. This building contains hydraulic presses, crane, pumps, and gas engine to drive them; and rooms for handkerchiefs, for ornamenting, and for packing finished goods.

The north wing, a fire-proof building of five flats, 299 feet by 46 feet, is the preparing mill. The first flat is used for tow-carding and preparing; the second and third for flax or line preparing, which includes spreading, drawing, and roving; the fourth flat for rough hand and machine hackling; and the fifth for hand hackling and sorting. The east end communicates with the spinning mill by stairs and hoist through a building 26 feet by 16 feet, having six flats, of which the second, third, fourth, and fifth are used for storing rove on its way to the spinning mill, the sixth for reeling-room stores, and the first flat with addition is the engineers' shop.

The spinning mill, 221 feet by 42 feet, has six flats, and contains 32,000 spindles. The first flat is used for hackle-makers' shops, engineers' stores, wood turning and fluting shop, and weaving, beetling, cropping, and lapping rooms; the second, third, fourth, and fifth flats are wet-spinning rooms; and the sixth is a reeling room, from which there is a wire tramway 103 feet long to the drying loft, on the third flat of the boiler houses.

On the south side are three buildings occupied as offices, sale rooms, yarn store, and stock and lapping rooms, and containing lapping and measuring machines.

In the quadrangle are eight Lancashire boilers, and three beam-engines with Corliss valves. One engine with 35-inch cylinder and 5 feet stroke, making 45 revolutions per minute, drives the preparing mill. The two others, with 35-inch cylinders and 7 feet stroke, making 32 revolutions per minute, drive the spinning mill. For driving the weaving factory and heavy finishing machinery there are four Lancashire boilers supplying steam to two beam-engines with 38-inch cylinders and 7 feet stroke, which have wrought-iron beams and Corliss valves, and make 29 revolutions per minute; they drive two main shafts direct off the fly-wheel. The several sets of engines develop about 1,400 horse-power.

At the south-east corner is a five-flat building, in which the first flat is used for weaving, the second for pirn winding, the third for yarn dressing and beaming, the fourth for hank winding, and the fifth for dressing. Adjoining is another building, in which the first flat is used for heavy finishing machinery and pirn stock-room, the second for pirn winding, the third for beaming, and the fourth for hank winding and beaming. In an adjacent building the first flat is used as a drawing-in shop and beam stock-room, and the second as a cloth-passing room, from which a carrying band conveys the cloth through 138 feet distance to cropping machines on the first flat of the spinning mill. The weaving sheds contain about 1,000 looms for plain and damask linens. Bleaching is carried on in works at Muckamore, County Antrim.

ROPE AND TWINE MANUFACTORY, CONNSWATER.

These works, belonging to the Belfast Ropework Co., are employed in the manufacture of ropes, cords, twines, lines, gaskettings, plaited sash-cords, and sundry other articles of a similar description. They occupy an area of twelve acres, about eight of which are under cover. The engines are compound vertical, 800 indicated horse-power; and about 1,000 persons are employed.

ROYAL ULSTER PRINTING AND STATIONERY WORKS.

These works, the property of Messrs. Marcus Ward and Co., have a floor area of over four acres and contain nearly 1½ million cubic feet. The building was erected in 1874 to suit the special requirements of the rapidly increasing business. The works are arranged in the form of the letter T, with five lofty storeys, reached by a central granite staircase and also by a lift. Each storey is divided into two portions by fire-proof walls and iron doors. On the ground floor are the front offices, the sales and sample departments, the stores, where large quantities of paper and other materials are kept in stock, and the machine-rooms. The lithographic printing department is on one side of the building, and contains the lithographic stones arranged vertically in wooden racks, and numbered and registered. The letterpress printing department is on the other side of the building; some of the machines print on both sides of the paper at once, and others print several colours at one operation. Railway-ticket printing, photo-lithography, photo-zincography, electrotyping, and stereotyping are carried on in an adjoining building. On the top floor, reached by means of the lift, are carried on the processes of enamelling in the various colours, mounting, gelatining, varnishing, gumming, &c.; also the making of cardboard and envelopes, black-bordering, and the preparation of stationery of every description. On the next lower floor is the book-binding department, containing many labour-saving machines. On the next floor below is the box-making department, for the preparation of fancy goods. On the next lower floor are the compositors', artists', engravers', and die-sinkers' rooms; also the

sample and board rooms, the directors' and managers' rooms, the travellers' sample room, and telephone rooms, &c. Amongst the specialities of these works may be mentioned the linen writing papers, which are made from pure linen cuttings collected from the linen factories in the north of Ireland.

ROYAL IRISH LINEN WAREHOUSE.

This building, the property of Messrs. Robinson and Cleaver, erected in 1887, has a frontage of 128 feet to Donegall Square, and of 78 feet to Donegall Place. The foundations of the building are formed by driving 500 piles, 40 to 45 feet long, the substratum consisting of 30 feet of river mud, locally called "sleech." Courses of heavy timber were bolted longitudinally and crosswise on the top of the piles, and each course was filled in with concrete. On the concrete were laid blocks of granite, from 3 to 5 tons, carrying piers constructed of solid fire-brick and cement, and shafts of polished Aberdeen red granite, with moulded bases and fluted caps, backed by iron stanchions of 7 tons weight, filled with concrete and surmounted by a frieze of dark green Swedish granite. From these rise the successive tiers of the superstructure, built of pure white sandstone, obtained from the Glebe Quarry, County Down. All the columns, of which there are over 250 dividing the windows, are of polished red granite with carved caps, no two being alike; the plinths are of polished black granite. The main building is nearly 90 feet high, with octagonal towers of about 120 feet height at two of the corners, and at the principal corner a circular tower, 150 feet high, from which a fine view is obtained of the town, harbour, and surrounding country; the cupolas of the towers are covered with copper. A hydraulic American elevator conveys passengers to the top storey of the building. The clock in the tower has two illuminated dials, each six feet diameter. The quarters ring the Westminster chimes, and the hours are struck on five Harrington tubes. The interior of the building is divided into eight floors, having a total area of 60,000 square feet. In the basement, which is lit by prismatic lights, are the boiler and engines for driving four dynamos for supplying electric arc and incandescent lights; a Worthington

steam-pump drawing water from a well 220 feet deep, and discharging 150 gallons per minute into a tank at the top of the building for driving the hydraulic lift &c.; air-pumps for supplying compressed air and exhaust for the pneumatic tubes which convey the cash from the counters to a central desk; a fire-proof strong room; and the receiving, packing, and despatching department. The ground and first floors are fitted as sale-rooms and are connected by a staircase of white Sicilian marble. They are provided with every convenience, including a ladies' parlour and suitably appointed fitting rooms, one of which can be instantaneously darkened for judging colours by artificial light. On the second floor, which is reached by a staircase of Australian jarrah wood, are the sample rooms, postal, despatch, and shipping departments, and the offices. The third floor is occupied with looms weaving handkerchiefs, linens, and table damasks of various kinds. Amongst these is a loom for weaving doyleys that measure 17 inches long by 15 inches broad; it contains 3,060 threads of warp and 4,012 threads of woof, for which the design was drawn on paper 12 feet long by 11 feet wide, divided into 12,000,000 squares. The loom is arranged to weave four doyleys at a time, and occupies a space over 12 feet in length and breadth, and 11 feet in height; it has five large jacquard machines, with 20,000 cards containing nearly 10,000,000 punched holes. From the machine there are 12,240 cords, with small weights attached, employed to lift the threads of yarn, and secured in position by 61,200 knots. A total weight of 428 lbs. is lifted at each throw of the shuttle. The upper floors are used as workrooms for shirt and collar making, handkerchief hemming and dressing, &c. A dining room and kitchen, with every facility for cooking by steam and gas, are provided on the top floor. The whole structure is heated by high-pressure steam. The wrought-iron gates which close the doorways at night are raised by machinery from the basement. The materials used in the construction of the building comprise 400,000 bricks; 30,000 cubic feet of sandstone; 29,000 cubic feet of timber; 360 tons of iron; 6,000 cubic feet of concrete; 4,300 square feet of polished granite; 11,500 square feet of polished plate glass; $25\frac{1}{2}$ miles of electric wire; 30,000 square feet of polished teak and

mahogany; and about 3,000 square feet of mirrors. The architects were Messrs. Young and Mackenzie, and the builders Messrs. H. and J. Martin, Belfast.

LINEN WAREHOUSE.

This warehouse, belonging to Messrs. J. N. Richardson Sons and Owden, was built in 1869 from the designs of Messrs. Lanyon Lynn and Lanyon; the interior is specially arranged for carrying on the linen business in all departments. The goods include every variety of linen fabric, such as handkerchiefs, damasks, towels, and white linens. After being bleached at the firm's extensive bleaching works in the neighbourhood of Belfast, they are sent to the warehouse, where they are lapped, folded, and ornamented.

AERATED WATER MANUFACTORY.

These works, belonging to Messrs. Cantrell and Cochrane, and covering nearly half an acre, are situated in the south-east part of the town, where the Cromac springs give a fine supply of water, which is obtained from a well 166 feet deep and is pumped by engines on the ground floor up to large cisterns at the top of the building; the consumption amounts to about 17,000 gallons per day. The carbonic acid gas is generated in large cylinders on the ground floor, and after repeated purification by washing is stored in gasometers, from which it is drawn by the aerating machinery on the bottling floor. In the laboratories on the second floor, the aerated waters are tested from time to time, and the various ingredients used in their manufacture are analysed. Here also are prepared the various syrups, in which the chief ingredient is sugar; after being filtered through peculiar filters they are poured into large slate tanks, from which the bottling machines on the floors below draw their supply. The vessels set apart for the syrups are all made of glass, porcelain, or slate, so that they can be easily cleaned. Preparatory to the bottling, the new and returned bottles are first thoroughly washed by a continuous process, being steeped in hot water, brushed inside and outside, and rinsed, and then passed down a slide to the bottling rooms. In the centre of the bottling room is

the powerful aerating machinery, which impregnates the water with carbonic anhydride in strong cylinders under a pressure of 140 lbs. to 150 lbs. per square inch. The water pumped direct from the well passes through a specially constructed filter into a slate cistern, which is covered with a glass lid and kept under lock and key to prevent contamination of any kind. The aerated water is then bottled and corked by the bottling machines, three of which are automatic rotary, and the rest are controlled by hand; the corks are wired by hand. The automatic machines are each fed by one man, and work at the rate of 180 dozen per hour; on the other machines each man is expected to work at the rate of 20 dozen per hour. The whole of the piping used is made of gutta percha and chemically pure tin, and the interiors of the cylinders of the machines are either silvered or enamelled. The bottles for home supply are packed in compartment cases, while those for export are doubly wired and wrapped in paper and packed in barrels between hay or straw.

PRINTING WORKS.

These works, belonging to Messrs. David Allen and Sons, consist of two parallel buildings; the intervening space is covered over with a glass roof, and forms the litho poster machine-room, which contains the largest litho machines made. The stones are of unusually large size, measuring almost four feet by five feet and weighing about 10 cwts., and are imported from Germany. They are sold by weight, the price per pound increasing with the size. Before being used they are polished and grained by machinery, and after being etched and gummed are conveyed to the machines by overhead tramways, frames being also provided for carrying the sheets on a tramway to and from the machines, and to the drying racks. Most of the work is printed on double quad crown sheets measuring 60 inches by 40 inches. The litho machine-printing is performed on the first floor of the front building by means of a dozen machines, almost all of large size and of the latest construction. The bronzing of the sheets is performed in an adjoining room, into which they are passed through apertures, so that no bronze can escape into the machine room. Extending to the left on this floor

is a room devoted to the sorting of posters. In this room also, if the work is to be preserved after printing, the stones after being gummed up and labelled are stored away in racks. On the floor above is the composing room, and also the letterpress machine-room, containing upwards of a dozen large machines, on some of which two colours can be printed simultaneously. The third floor is entirely monopolised as a stock room, and for warehousing purposes. The photographic gallery and enlargement room occupy the fourth and highest floor. The first floor of the rear building is devoted to bookbinding, paper-ruling, label-punching, gumming, varnishing, and other similar work. On this floor also are two ink mills, in which are made all the coloured inks. The artists' department is on the second floor, which is lighted entirely from the roof. When a sketch has to be reproduced in an enlarged form as a poster, it is first traced, then enlarged to the size required in conté crayon, and rubbed down upon specially prepared stones, each of which corresponds in size to a sheet of the poster. The sketch itself is cut into corresponding sections, one of which is given to the artist in charge of each stone, who reproduces that portion of the sketch. In this way a placard of about 100 square feet, which in ordinary working would involve the printing of about 100 stones, can be turned out in a fortnight. On the basement is the wood-cutting department, all the wooden blocks in use being cut on the premises; and also a hot-water apparatus for heating the premises during the winter months.

BELFAST CORPORATION GAS WORKS.

These works were originally constructed in 1822, and in 1852 were placed under the management of Mr. James Stelfox, the father of the present manager. Since the acquisition of the works by the Belfast Corporation in 1874, numerous appliances have been provided for the despatch of work and saving of labour, including an extensive hydraulic plant, chiefly supplied by Sir William Armstrong and Co., for the discharge of coal, the storing of coke, and other similar work. As the town has increased with a rapidity almost without parallel, the works have been extended

proportionately. The quantity of gas made in 1852 was 87,870,000 cubic feet; in 1862 it was 173,939,000 cubic feet; in 1872 it was 410,000,000 cubic feet; in 1882 it was 614,791,000 cubic feet; and in the year ending 30 June 1888 it has reached 853,154,000 cubic feet. The Claus system is about to be tried for purifying the gas by the complete neutralization of the acid impurities which it contains. With this object a sufficient supply of ammoniacal gas is introduced, and the resulting salts are then dissolved in a series of closed vessels by liquor supplied from a series of pumps. The liquor containing these impurities is kept in circulation, the carbonic acid and sulphuretted hydrogen being driven off in specially designed vessels; the sulphuretted hydrogen goes forwards to the sulphur kilns, in which the sulphur is recovered in a saleable form and the hydrogen consumed. This system it is hoped will prove completely successful, as the process is a continuous one, conducted in closed vessels, and would thus no doubt obviate the smells connected with gas works.

ORMEAU BRICK WORKS.

Situated about 1½ miles from the Exchange by the side of the river Lagan, these works form an important extension of the plant of Messrs. H. and J. Martin, and are perhaps the largest of the kind in the kingdom. On both shores of the Lagan, extending for several miles above Belfast, occur deposits of useful clay, overlying red sand; these vary from 2 to 100 feet in thickness, and are unusually free from foreign ingredients, the only impurities consisting of minute pieces of lime in a soft or chalky condition and a few carried boulders. The composition of the clay, when mixed with a proportion of the underlying sand, is most suitable for brick and tile making; no puddling is required, and the material is only once turned over for the purpose of removing any large stones and mixing the sand in.

The machinery, which has been started this season, is at present arranged to turn out 60,000 perforated bricks per day of ten hours. It consists of a set of five horizontal rollers, 30 inches diameter and 4 feet 6 inches long, geared together and arranged in such order that

the clay undergoes three successive pressings of increasing closeness; in the last the rolls are almost in contact. The material is hauled up an inclined railway from the pit, and dumped into the roller hopper, no special arrangement being required for feeding it. From the roller mill it falls by gravity into two vertical pug mills, in which revolve upright shafts armed with angular blades and furnished with cams at the bottom; the blades are so set as to force the clay down, and the cams, which are made in helical form, drive it out through two horizontal dies in each mill. These dies are fitted with cores for making perforated or other bricks, and the stream of clay is forced through them on to cutting tables, where it is divided, ten bricks at a time, into the necessary sizes. As it is of considerable importance to work the clay as firm as possible, since the green bricks then require less air-drying and are more easily handled, all parts of the machines are made extra strong; steel shafting and gearing are adopted throughout. It is only in dry summer weather that any water is mixed in with the clay; at other times it is worked as it comes from the pits, and the bricks made from it in that condition are so firm that they can at once be handled. The works are driven by a horizontal compound engine indicating about 200 H.P., with Corliss valves on the high-pressure cylinder, and using steam supplied by an ordinary Lancashire boiler at 80 lbs. pressure.

From the mill the bricks are wheeled by hand to the drying ground, whence after sufficient exposure to the air they are transferred in trucks running on a portable railway to the kilns. A comparatively short time on the drying ground suffices, as the perforations greatly facilitate evaporation as well as the subsequent firing. Hoffmann's kilns are used; these consist of a series of sixteen chambers arranged in oval form and with a chimney in the centre. The flues are so constructed that each chamber can be connected to the uptake and to its neighbours in succession. The capacity of each chamber is 13,000 bricks. Firing is continuous and most economical, the only heat lost being the radiation from the walls of the kiln and the necessary chimney draft. The products of combustion from any chamber which for the time being is at full

heat pass through the chambers to follow, thereby drying and warming them up; while its supply of air is drawn through the hot bricks in those which have preceded it, thereby cooling them and adding to the efficiency of the combustion. The fuel required is about half that used in the ordinary kilns.

The machinery was made by Messrs. Victor Coates and Co. of Belfast, Mr. A. Basil Wilson being the consulting engineer.

FALLS FOUNDRY AND ENGINEERING WORKS.

These works, the property of Messrs. Combe Barbour and Combe, were commenced in 1845 for the manufacture of machinery for preparing, spinning, and twisting flax. They have steadily increased in size and in power of production, and their present output includes all the machines required for preparing, spinning, and twisting flax, hemp, jute, manilla, sisal, and other similar fibres, ranging from the finest yarns that are used in the manufacture of lace, to the coarsest yarns for twines and ropes; and also engines, shafting, and all millwright and fire-proof work, as well as all the accessory machines and special tools required in mills and factories. A very large variety of special tools are here in use. It was in these works that rope driving originated (Proceedings 1876, page 392), and it is interesting to note that the first pair of rope pulleys made for main driving purposes, nearly thirty years ago, are still at work here. The works occupy an area of five acres, and the covered floor area is over 200,000 square feet; upwards of 1,400 hands are employed. The power is supplied by six boilers, and three condensing and nine non-condensing engines.

BELFAST HARBOUR.

The first quay at Belfast was constructed as early as the beginning of the seventeenth century, but no works of magnitude were attempted in the harbour until the close of last century, up to which period the channel was shallow and circuitous, and the harbour without a dry dock. Large sums of money have since been expended on improvements. The docks and basins now cover an area of 36 acres, and are surrounded by 17,000 feet of quays; a floating dock which

admits vessels drawing 23 feet, and two slipways, one of which receives vessels of 1,000 tons burden, and four graving docks, have been constructed as demanded by the requirements of trade. The Alexandra graving dock, now on the eve of completion, is one of the largest in existence; its length is 800 feet, width of entrance 80 feet, depth 25 feet, width of floor 50 feet, and depth from coping to floor 31 feet. The principal quays are constructed of concrete, faced and coped with granite, and are provided with superior goods sheds, and traversed by tramways which connect the harbour with the various railways. Modern mechanical appliances have been provided for the rapid and economical handling of goods. Small steam cranes, capable of lifting loads of 2 tons at a radius of 40 feet, and at the rate of 40 tons per hour, are placed on the principal quays. A steam derrick crane, capable of lifting loads of 100 tons at a radius of 50 feet, will shortly be placed at the Alexandra graving dock; and a 25-ton steam crane will soon be fixed on Princes quay for the accommodation of steamers arriving or departing with ponderous articles. The new straight deep-water channel in continuation of Victoria Channel is being dredged to a depth of 26 feet, which is the depth of the present channel from the north end of the Twin Islands to Queen's bridge. Two powerful steam hopper dredgers, each capable of loading itself with 800 tons of spoil in 40 minutes, have been employed night and day for more than two years at this work, which is rapidly approaching completion. The revenue of the harbour for the past year was about £109,000; fifty years ago it was £9,600. The tonnage which entered the port in 1887 was 1,670,000, while in 1837 it was only 288,000. The extent of the manufacturing industries may be inferred from the import of coal, which last year amounted to 850,000 tons. The flourishing shipbuilding yards on both sides of the river, as well as the ample storage accommodation provided in the vicinity of the docks, are situated on ground which has been reclaimed from the lough.

These particulars have been kindly furnished by Mr. W. A. Currie, Secretary to the Belfast Harbour Commissioners.

DESCRIPTION OF MEW ISLAND LIGHTHOUSE, BELFAST LOUGH.

By Mr. WILLIAM DOUGLASS,
Chief Engineer to the Commissioners of Irish Lights.

This Lighthouse was lighted on 1st November 1884, and the usual bright and welcome beam was missed from the tower on the neighbouring Lesser Copeland Island, Plate 81, for the first time since 1816. In 1796 the Revenue Board exhibited a beacon fire of coals from a tower a few yards distant from the present site of Copeland tower; this was transferred in 1810 to the Dublin Ballast Board, who in 1813 commenced a new tower and dwellings, which were completed in 1816 from the designs and under the direction of Mr. G. Halpin.

During the days of sailing vessels Copeland light appears to have satisfied the requirements of the mariner. Later on, as steamboats increased in number and power, making straight courses where possible, and rounding points closely to reduce the mileage, it became evident that Mew Island was the proper place, especially during fog or haze, for a lighthouse intended to guard the southern turning point into Belfast Lough, Plate 81, and also for the general navigation of the coast by passing vessels. Several years elapsed however before an estimate was sanctioned by the Board of Trade for building the present Mew Island lighthouse station.

As seen from Plate 81, Mew Island forms the turning point for vessels entering Belfast Lough from southward, lying eastward of the Lesser Copeland, from which it is separated by a shallow channel only a few fathoms wide at low water. It is a low island, about 26 acres in extent, as shown in Plate 82. The site of the new lighthouse tower is in latitude 54° 41′ 50″ N and longitude 5° 31′ 30″ W, being 383 fathoms N 87° $11\frac{1}{2}$′ E of the old Copeland tower. As shown in the ground plan, Fig. 3, and south elevation, Fig. 4, Plate 83, the station consists of a circular tower 98 feet high, Plate 84, the centre of light being 121 feet above high water, and

the total height of tower from base to vane $129\frac{1}{2}$ feet; a dwelling for lightkeepers, having a messroom and four bedrooms; a retort house, 24 feet by 22 feet; coal stores for cannel coal and furnace coal, each 25 feet by 10 feet 7 inches; a fog-signal house, 30 feet by 21 feet; and two gas-holders of 25 feet diameter, each having a capacity of 4,600 cubic feet. There is also a shore station near Donaghadee, Plate 81, with commodious dwellings and gardens for five keepers; a boat slip, and a boat house with store above. The lighthouse tower, Plate 84, is of rubble masonry in Portland cement, stuccoed in Portland cement, with granite dressings; the other buildings of rubble masonry in lime mortar. The stone for the rubble work was quarried on the island, and the granite obtained from the neighbourhood of Newry.

The light is triform group-flashing, exhibiting a group of four flashes every minute; the group occupies 20 seconds, and the interval between the groups 38 seconds; the length of each flash is 4 seconds, and the eclipses between the flashes are each $1\frac{1}{4}$ second. The illuminating agent is cannel gas, consumed in three super-imposed burners of 108 jets each. In clear weather 32 jets only of the lowest burner are used, equal to 491 candles; in hazy weather all the jets in this burner are lighted, equal to 2,923 candles; and during fog all the jets in all the burners, or a total of 324 jets, thus increasing the power of the beam when observed through the lenses from the normal power of 13,645 candles for clear weather, to 189,446 candles during fog.

Lantern.—The lantern surmounting the tower, Plate 84, is placed on a cast-iron gallery, having a diameter of 21 feet; it has sixteen sides, with sloping roof, and measures from top of gallery to top of vane 30 feet 4 inches; the internal diameter is 14 feet, and the height of the glazed portion 13 feet 8 inches. The pedestal is composed of sixteen cast-iron plates, 5 feet high, securely bolted together; these are fixed to the gallery course by thirty-two $1\frac{1}{4}$-inch bolts. The plates are faced inside with polished mahogany, with a suitable ventilator for each plate. The framing for the glazed portion is formed of sixteen vertical wrought-iron bars, $4\frac{1}{2}$ inches by $1\frac{1}{4}$ inch, and two horizontal

bars on each face, thus forming spaces for forty-eight panes of $\frac{3}{8}$-inch plate-glass. The vertical bars fit tightly into recesses formed in the pedestal plates at the joints, where they are secured by four $1\frac{1}{8}$-inch bolts. All the sash-bars are rebated on the outside to receive the glass and putty, the glass being further secured and the joints made watertight by copper capping pieces, which cover the edges of adjoining panes, and are fixed to the sash bars by suitable screws. The tops of the vertical standards support a wrought-iron cornice plate, 6 inches by $\frac{5}{8}$ inch, to which they are secured by tap bolts; to this cornice plate the top cill, copper gutter, and lower ends of the rafters are bolted. The roof is formed of copper plates weighing 3 lbs. per square foot, supported on sixteen T iron rafters, whose lower ends are bolted to the cornice plate, and their upper ends to a central wrought-iron flanged connecting-ring, 3 feet diameter, over which is fixed a copper revolving cowl, hammered to shape, accurately balanced, and surmounted by a vane. The lantern floor is of cast-iron, in two annular rings; the outer is perforated in order to allow a free flow of air from the room below, in which are four windows so arranged as to admit the air required for the burners and also for keeping down the temperature when all the burners are in use.

Optical Apparatus.—This consists of a circular cast-iron pedestal, 6 feet diameter, formed of cast-iron frames filled in with glass panels and fitted with glazed doors. In it is placed the rotating machine, and on its top is securely fixed a turned steel ring, on which travel eight cast-steel rollers, $5\frac{1}{2}$ inches diameter. The rollers support a cast-iron table, on which are fixed three tiers of lenses, with six panels in each tier. Each panel is 3 feet $8\frac{1}{2}$ inches wide by 4 feet $1\frac{1}{4}$ inch high, consisting of a central lens and eleven rings, or twenty-three elements in each panel, having a focal distance of 920 mm. They were made in Paris by Messrs. Barbier and Fenestre.

The rotating machine is driven by weights, having a fall of 40 feet; about 7 cwts. is required, which travels in a recess formed in the wall of the tower. In addition to revolving the lenses, the machine causes the gas valves to open and close at the intervals of

time corresponding with the length of the flashes and eclipses. It is also arranged to work an occulting apparatus in connection with an oil lamp, which is kept in readiness for use if the gas supply at any time should fail.

Fog Signal.—The fog signal is in duplicate, so that should one be under repair the other would be available for use when required. Each signal consists of an air compressor worked by a Crossley's 8-H.P. Otto silent gas-engine; a wrought-iron receiver, capable of storing 110 cubic feet of air; two sirens, one for a high note and the other for a low; and a copper trumpet. The character of the signal is a blast of four seconds' duration on the low note, followed after a silence of twelve seconds by a second blast of four seconds on the high note, succeeded by a silence of one hundred seconds. The sirens are supplied with air at a pressure of 40 lbs. per square inch, and when working are driven by the engine at a speed of 1,200 revolutions per minute. The high-note siren has thirty-two ports of 1·25 inch by 0·10 inch, and the low-note fourteen of 1·25 inch by 0·20 inch; thus giving 640 vibrations per second for the former, and 280 for the latter. The valves for supplying the compressed air to the sirens at the proper intervals and during the time necessary for each blast are worked automatically from the engine.

Gas Supply.—To meet the irregular consumption of gas owing to the variable duration of fog, the retort bench is provided with seven retorts, namely: two single settings, one double, and one treble setting. After three years' experience of the station, a single retort has been found to be sufficient, excepting on one occasion. The average consumption of gas is 525,173 cubic feet per annum.

Cost.—The amounts of the several contracts were:—buildings on island, £5,950; dwellings on shore, £3,200; lantern, optical apparatus, gas plant, and fog signal, £7,655; total, £16,805. The total cost, including purchase of Mew Island, superintendence, and legal expenses, was £19,008. Messrs. Dixon and Co. of Belfast

were the contractors for the buildings on the island; Messrs. Edmundson and Co. of Dublin for the lantern, optical apparatus, gas plant, and fog signal; and Mr. H. Fulton of Belfast for the shore station. The work was commenced in September 1882, and the light exhibited on 1st November 1884.

MEMOIRS.

Thomas Russell Crampton was born at Broadstairs, Kent, on 6th August 1816, and after receiving a private-school education was articled on 21st May 1831 to Mr. John Hague, of Cable Street, Wellclose Square, London. After serving his time, he acted during the years 1839–1844 as assistant to the elder Brunel, and subsequently to Mr. (now Sir Daniel) Gooch, under whose directions he prepared the drawings for the first locomotive for the Great Western Railway. Four years were then spent under Messrs. John and George Rennie on various important works; and in 1848 he commenced practice on his own account as a civil engineer. In the "battle of the gauges" he took an active part in favour of the narrow gauge. During the years 1842–1847 he made several improvements in the details of the locomotive engine, and embodied his ideas in the design of engine bearing his name, of which the characteristic features are—a long boiler, outside cylinders set in the middle of the engine's length, and a low centre of gravity, obtained by placing the driving wheels behind the fire-box. These departures from received practice formed the subject of a paper to the Institution of Civil Engineers in 1849. One engine only was built in England on this plan, the "Liverpool," weighing 35 tons, which ran on the London and North Western Railway till 1852, when it was withdrawn in consequence of being too heavy for the permanent way then in use. It was shown at the Great Exhibition of 1851, and won for its inventor the grand medal. The Crampton engine met with considerable favour on the Continent, especially in France, where for nearly forty years the light express trains of the Northern and Eastern Railways have been, and still are in the case of sections having easy gradients, worked by these engines. The satisfactory results obtained from thirty-five years' working led him in 1885 to design a new engine with four cylinders and large driving wheels, suitable for meeting the ever-varying demands of speed and tractive power, with fewer repairs and with a minimum of danger (Proceedings 1886, page 527). A small engine of this kind for 18 inches gauge was regularly at work at Woolwich arsenal for some time during 1887.

The most distinguished work of his professional life was probably the laying in 1851 of the first practical submarine cable between Dover and Calais. After the failure of a previous cable laid in 1850 by Mr. Brett, a second cable was prepared in 1851; but the laying was surrounded by serious difficulties, pecuniary and otherwise. The period of concession was within seven weeks of expiration when Mr. Crampton, contributing with his friends the capital required, undertook the whole engineering responsibility of constructing and laying the cable, and directed the operations to a successful issue before the closing of the Great Exhibition on 25th September 1851. He may therefore fairly be considered as the father of submarine telegraphy.

Amongst the various works that he carried out, either alone or in conjunction with others, may be mentioned the Berlin Water Works, which he constructed jointly with the late Sir Charles Fox; the Ottoman Railway from Smyrna to Aidin; the Varna and Rustchuk Railway; the East Kent Railway from Strood to Dover; the Herne Bay and Faversham Railway; and the line from Sevenoaks to Swanley. These latter lines became merged eventually into the London Chatham and Dover Railway, of which he was subsequently interested in the construction of other portions also. This railway was opened with six locomotives built in 1857 and fitted with steam-jacketed cylinders designed by him (Proceedings 1886, page 397).

He invented a rotary dust-fuel furnace, which was used for some time in Woolwich arsenal, and of which he gave a description to this Institution in a paper on mechanical puddling (Proceedings 1876, page 244); also brick-making machinery, a plan of cast-iron forts, and an automatic hydraulic tunnel-boring machine. The last was designed with special reference to the execution of the Channel Tunnel, and was fully described in his lecture to this Institution at Leeds (Proceedings 1882, page 440). In 1851 he started the Broadstairs gasworks, subscribing a large portion of the capital, and eventually constructing the works. He also originated and built the waterworks there, and presented the church with its clock. He was elected a Member of this Institution in 1847, the year of its commencement, and became a Member of Council in 1879, and a

Vice-President in 1883. He was an officer of the Legion of Honour, and of the Prussian Order of the Red Eagle. He died at his residence, 19 Ashley Place, Westminster, on 19th April 1888, in the seventy-second year of his age.

Charles Markham, J.P., of Tapton House, Chesterfield, was born at Northampton on 1st March 1823, being the seventh child of Mr. Charles Markham, clerk of the peace for the county of Northampton, which office has been held by a member of the family for nearly a century. After being educated at Oundle in Northamptonshire, he commenced his business career as manager of the Marquise Iron Works and Rolling Mills, near Boulogne, being a partner in this undertaking with Mr. James Morrison. The revolution of 1848 having destroyed this industry, he returned to England and studied chemistry for twelve months under Professor Scoffern. He then joined the engineering staff of the Great Eastern Railway, which position he relinquished upon receiving in 1851 the appointment of assistant locomotive superintendent on the Midland Railway, under Mr. Matthew Kirtley. It was here that he first came prominently before railway engineers, in connection with the introduction of coal as fuel in locomotives, instead of coke. The difficulties to be surmounted were of two kinds: firstly, raw coal when burnt by itself created a most offensive smoke, and the smoke-boxes were continually getting red-hot, in consequence of the small bits of coal being drawn through the tubes and firing in the smoke-box, thereby causing it to draw in air, and rendering it impossible to keep up the full pressure of steam; secondly, the ends of the tubes were soon eaten away by the intense heat in the fire-box, and had to be renewed in a very short time. After a prolonged series of experiments he finally determined upon the brick arch, deflecting plate, and jet pipe; and this system has not since been materially altered or improved upon. In 1860 he read a paper before this Institution, giving a detailed account of his researches into this most important matter (Proceedings 1860, page 147), whereby he estimated that a saving of £50,000 per annum was effected in the locomotives then running on the Midland Railway. He was also a

great advocate for the reduction of railway fares, and materially assisted in bringing about the abolition of second-class carriages on the Midland Railway. In 1864 he became the managing director of the Staveley Iron Works, near Chesterfield, previously belonging to Mr. John Barrow; this position he continued to hold to the time of his death. Under his management these works, from being comparatively a small undertaking, increased so as to be now one of the largest foundries in the country, capable of executing the most difficult class of foundry work. He became a Member of this Institution in 1856; and in addition to the paper on coal burning in locomotives he contributed also a paper on Naylor's double-acting steam hammer (Proceedings 1857, page 233), and a description of a new safety coupling for railway wagons (Proceedings 1860, page 277). After a severe illness of more than a year's duration, he died on 30th August 1888, in the sixty-sixth year of his age.

WILLIAM MUIR was born at Catrine, a village in Ayrshire, on 17th January 1806, being the son of Mr. Andrew Muir, farmer and contractor, of that place. He early evinced a liking for mechanical pursuits, and after receiving an ordinary middle-class education was bound apprentice to Mr. Thomas Morton of Kilmarnock, with whom he stayed for five-and-a-half years. In 1824 he entered the employment of Messrs. Girdwood and Co. of Glasgow, makers of cotton spinning machinery, into which class of work he had already obtained some previous insight in connection with the Catrine Cotton Works. While in Glasgow he attended classes at the university, and by study after work hours improved his knowledge of mechanics and mathematics. In 1829 he was again employed by the Catrine Cotton Company, who made their own manufacturing machinery; and in 1830 he spent some time in lathe work with Henry Houldsworth of Glasgow. On 7th September 1830 he left Scotland, and after visiting Liverpool proceeded to Cornwall, where on 18th October he commenced an engagement at Hayle Foundry. In March 1831 he left for London, and entered the shops of Messrs. Maudslay and Field, where he soon became a foreman. The work upon which he was there engaged presented a considerable range in variety,

including the construction of a steam carriage for use on common roads, with two cylinders acting direct on the crank axles, for carrying out the ideas of Admiral the Earl of Dundonald, then Lord Cochrane. At that time Mr. James Nasmyth was engaged at these works as draughtsman, and Mr. Joseph Whitworth as a fitter. In 1836, after spending six months with Mr. Holtzapffel as assistant and representative, he became foreman to Messrs. Bramah and Robinson, where he remained until 1840, when Mr. (afterwards Sir Joseph) Whitworth induced him to go to Manchester and become manager in his works. In this position he did much excellent work, and, besides being intimately associated with the elaboration of the Whitworth system of screw threads, he was also engaged in the design and construction of the road-sweeping machine, a new knitting machine, a radial die-box, a 6-inch screw-cutting foot-lathe, a new boring bar, a bolt-screwing machine, a small planing machine, a planing machine for circular work, and the radial drill. In June 1842, having made the acquaintance of Mr. Thomas Edmondson, the originator of the railway ticket, who was in need of assistance in the production of machines for printing the tickets, he started for himself in Berwick Street, Manchester, as a maker of railway-ticket printing machinery. The premises were soon outgrown, and jointly with Mr. Edmondson he took a large building in Miller's Lane, Salford, subsequently removing to Strangeways, Manchester, where he commenced the erection of the large establishment now known as the Britannia Works. In 1852 he supplied various labour-saving machine-tools and appliances for government use at Woolwich arsenal; and two years later, in connection with the establishment by government of the Enfield small-arms factory under the late Sir John Anderson, he designed and manufactured machinery for the construction of rifle-sights on the interchangeable principle. In connection with screw-cutting lathes he invented a releasing motion and an arrangement for making right and left hand screws, with other important improvements now in general use. Amongst his inventions were also improved drilling and milling machinery, a double grindstone in which by regulated contact two stones dress

each other and keep their grinding surfaces in fit condition, and many other machine-tools. His automatic machinery for winding cotton balls and bobbins is in very general use. Some years ago he retired from active business and settled at Brockley, London, where after a few months' illness he died on 15th June 1888, in the eighty-third year of his age. He became a Member of this Institution in 1863.

CHARLES WETHERELL WARDLE, senior partner in the firm of Messrs. Manning Wardle and Co., Boyne Engine Works, Leeds, was the son of a former vicar of Beeston near Leeds, and was born at Rothwell, near Leeds, on 21st January 1821. He learnt his profession under Matthew Murray, who constructed some of the earliest locomotives that were commercially successful, and whose inventions contributed in no small degree to the general prosperity of the flax trade. After completing his apprenticeship he went to the Milton Iron Works as improver, and later to Messrs. E. B. Wilson and Co., Railway Foundry, Leeds, as general manager, eventually becoming chief engineer and outdoor representative. At that time the Railway Foundry was one of the largest locomotive and general engineering works in the country; and being thus brought into frequent contact with the locomotive superintendents and directors of most of the large railways both in this country and on the continent, he became well known in the railway world. On the closing of the Railway Foundry in 1858, he entered into partnership with others who had held important positions there, and commenced the Boyne Engine Works on a portion of the same site. In about fifteen years, owing to withdrawal or death of the other partners, the business devolved wholly upon himself and his son. In 1868 he was engaged by the government in valuing the railways in Ireland. His death took place at his residence, Linton Spring, Wetherby, on 3rd July 1888, in the sixty-eighth year of his age. He became a Member of this Institution in 1856, and in 1861 gave a paper on an application of Giffard's injector as an elevator for the drainage of a portion of the pit workings at Kippax Colliery near Leeds (Proceedings 1861, page 220).

AUTOMATIC SLUICE.

Sluice closed.

Fig: 1. *Plan.*

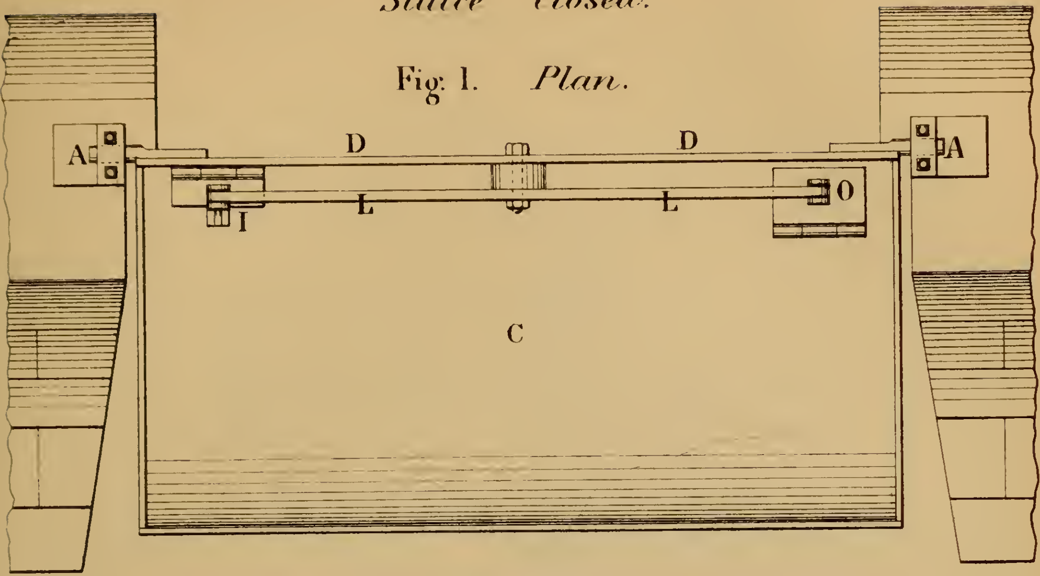
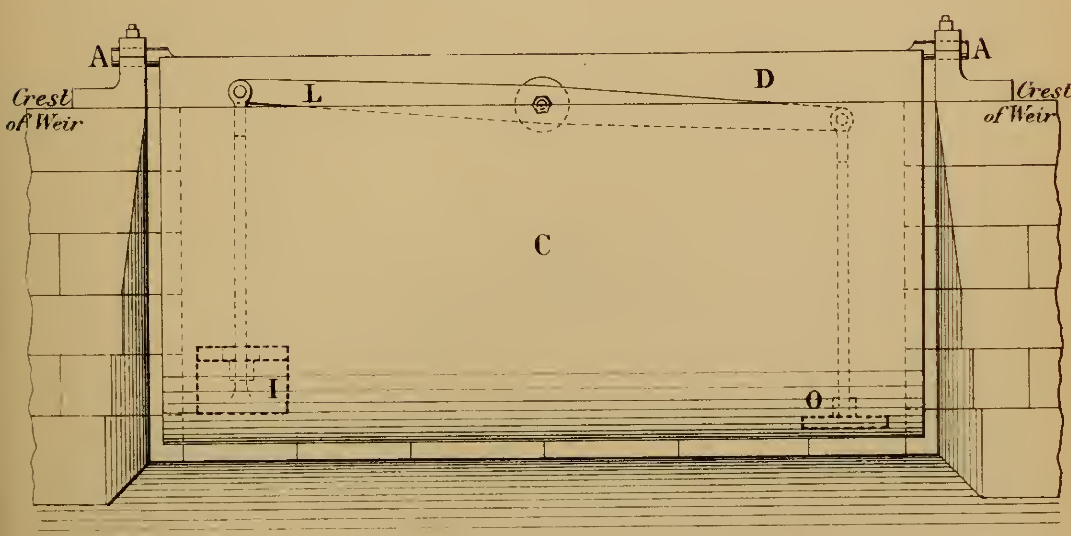


Fig: 2. *Back Elevation.*



Scale 1/24th

Transverse Sections.

Fig. 3. *Sluice closed.*

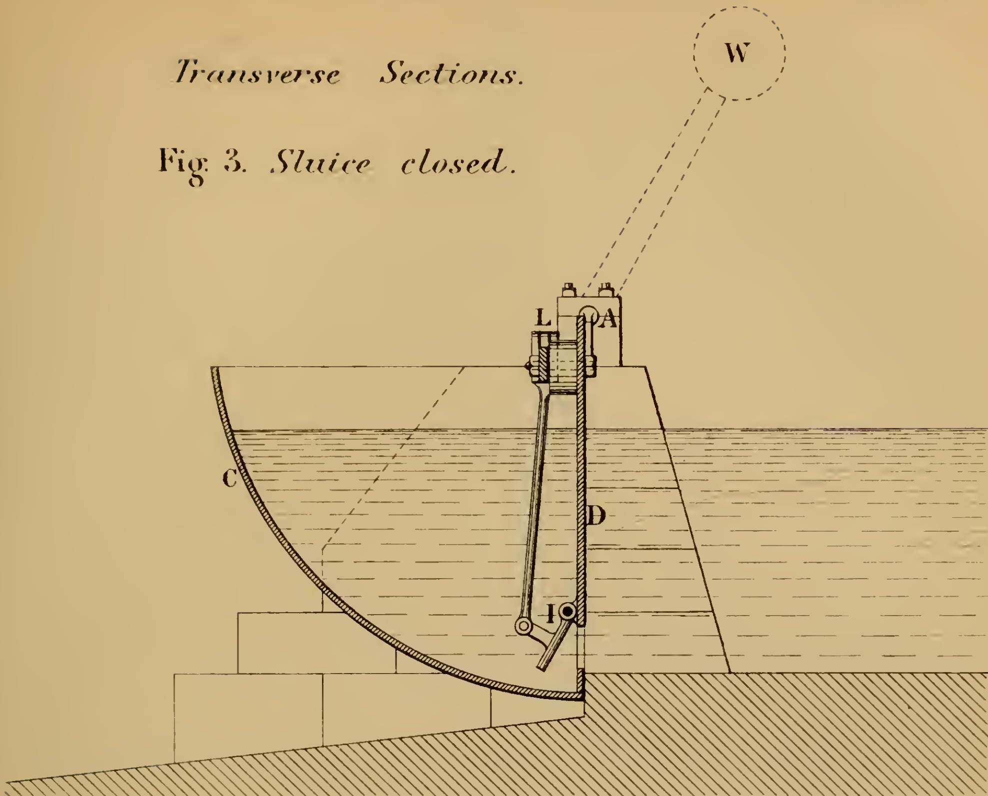
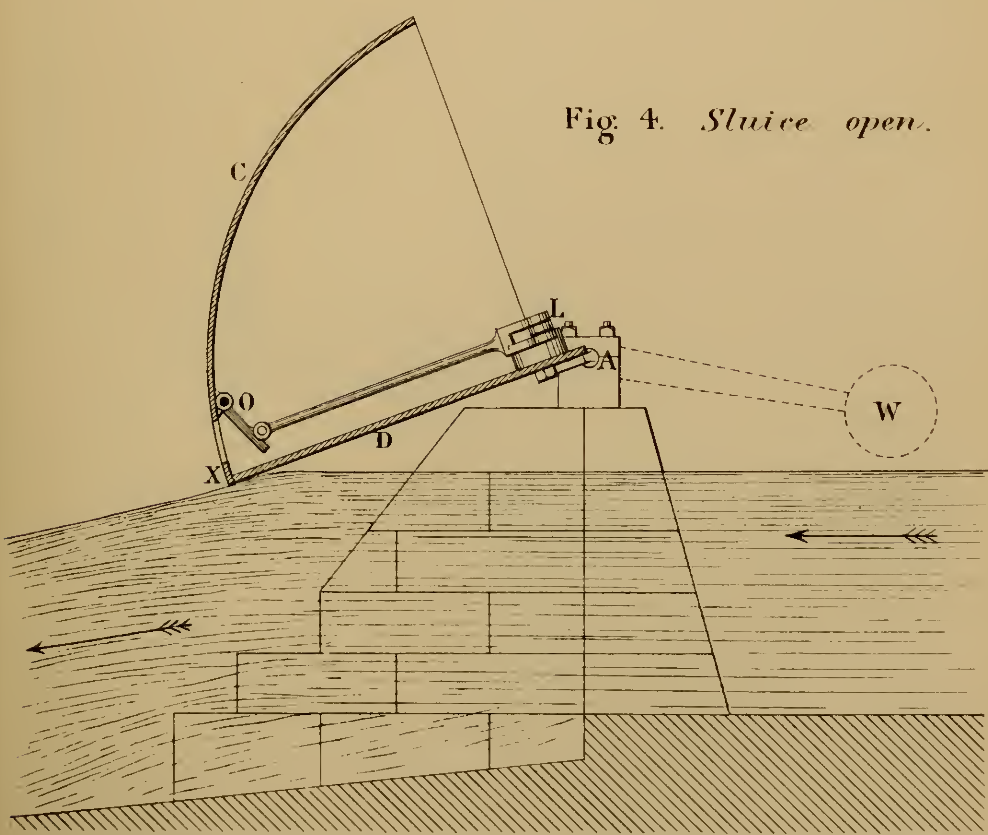


Fig. 4. *Sluice open.*



Scale 1/24th Ins. 12 6 0 1 2 3 4 Feet.

(Proceedings Inst. M. E. 1888.)

AUTOMATIC SLUICE.

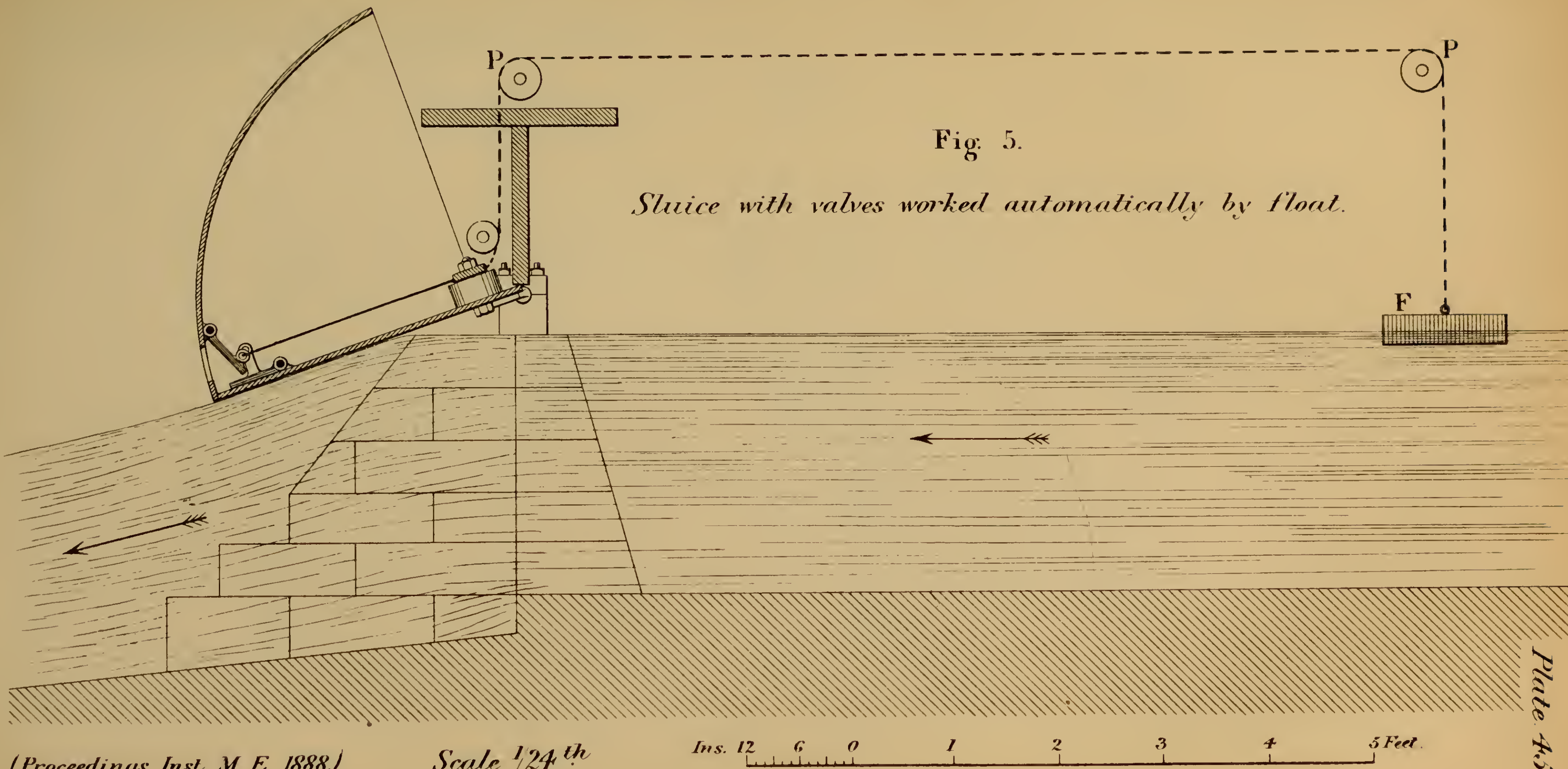


Fig. 5.

Sluice with valves worked automatically by float.

Scale 1/24th

(Proceedings Inst. M. E. 1888.)

Plate 45.

Second form of Electrical Control.

Fig. 1. *Sectional Plan.*

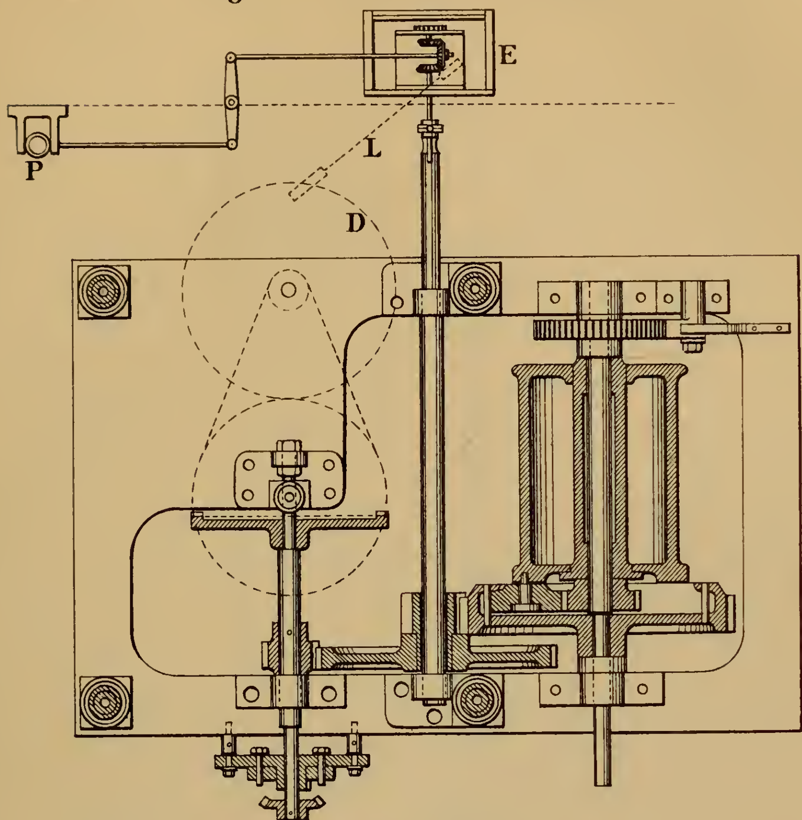
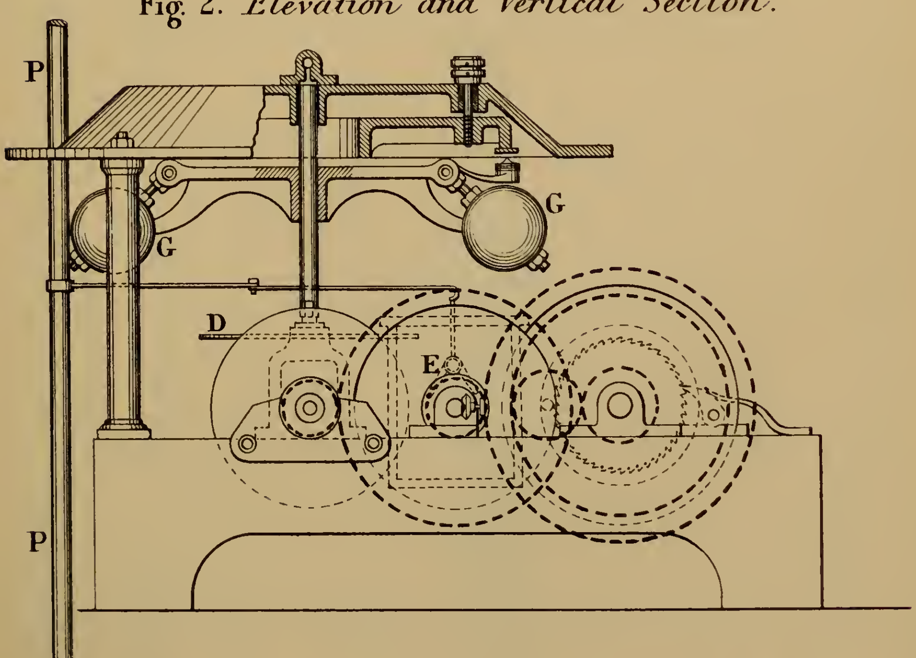


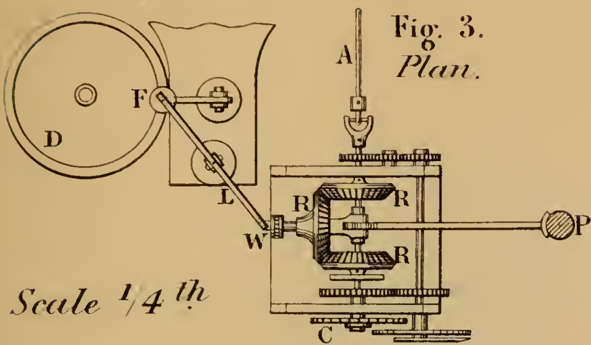
Fig. 2. *Elevation and Vertical Section.*



Scale 1/8 th

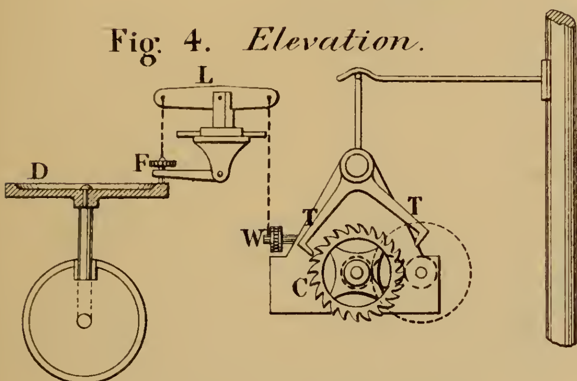
Second form of Electrical Control.

Fig. 3. *Plan.*



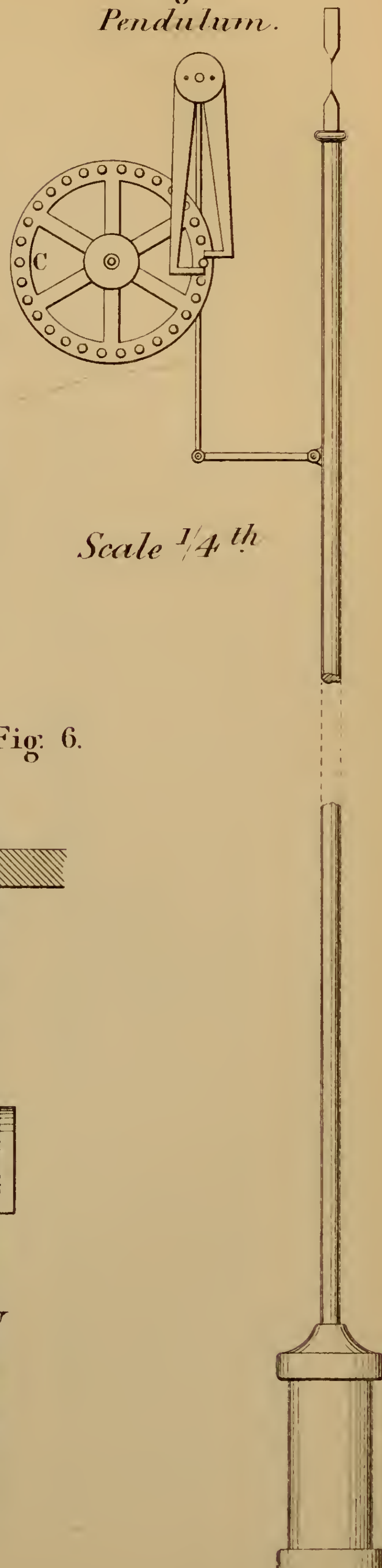
Scale 1/4th

Fig. 4. *Elevation.*



Third form of Electrical Control.

Fig. 7. *Pendulum.*



Scale 1/4th

Fig. 5. *Slow Motion in Declination.*

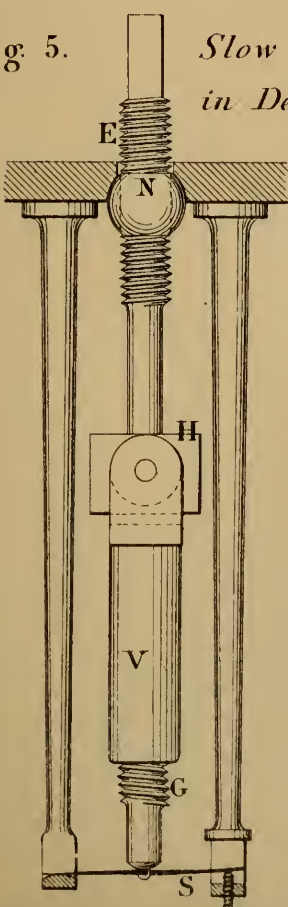
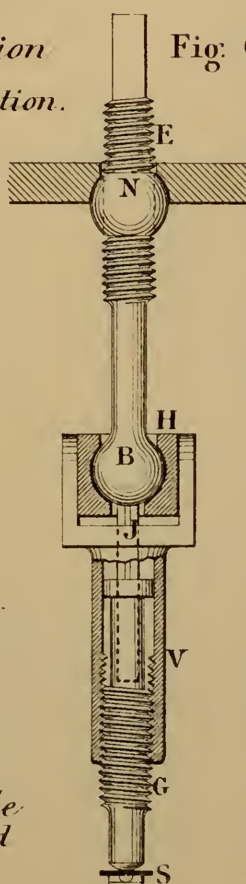


Fig. 6.



Scale 1/3rd

(Proceedings Inst. M.E. 1888.)

Third form of Electrical Control.

Fig: 8. *Plan of Detector and Correctors.*

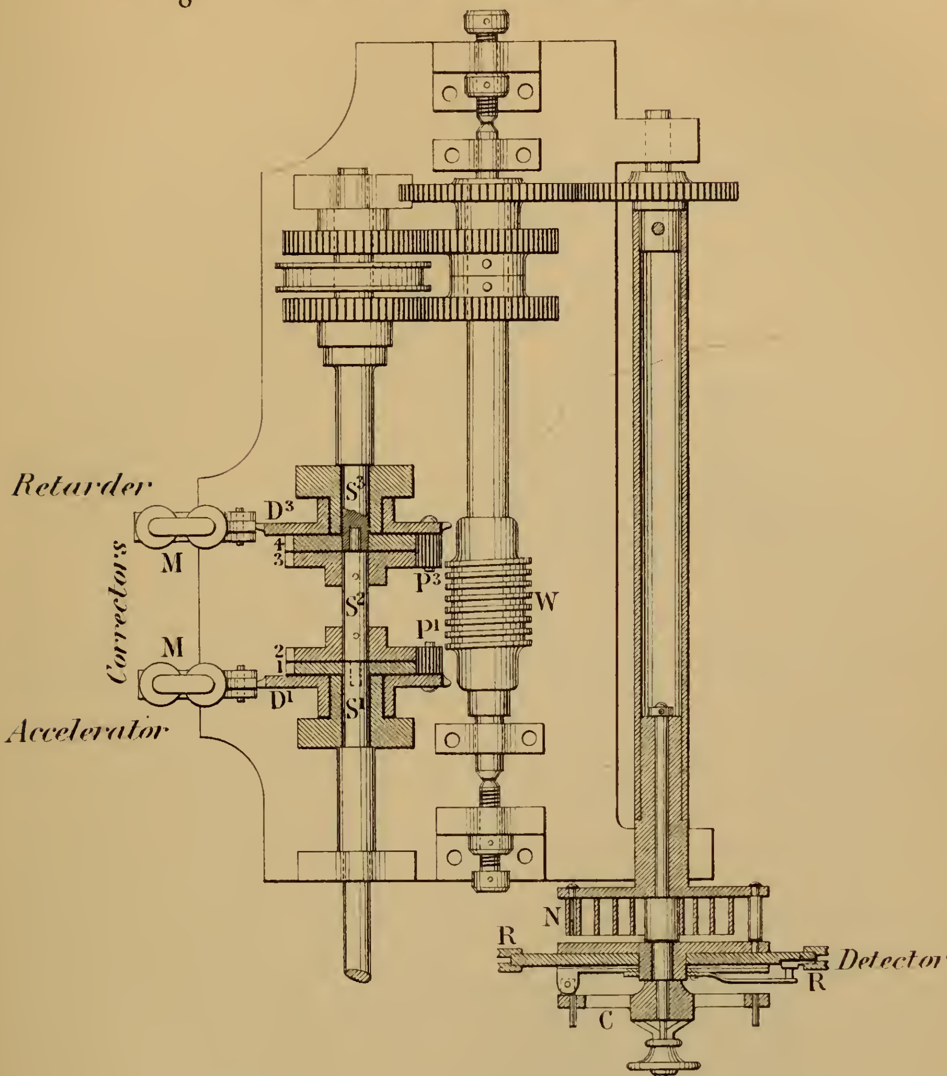
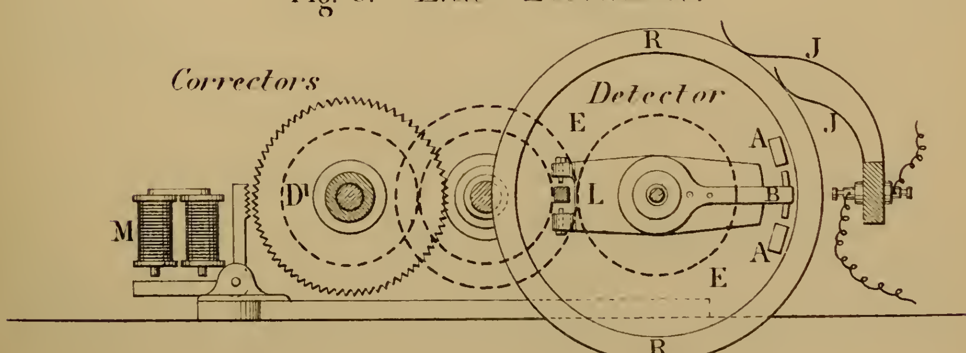


Fig: 9. *End Elevation.*



Scale 1/4th

Fourth form of Electrical Control.

Fig: 10. Plan. Scale 1/4th.

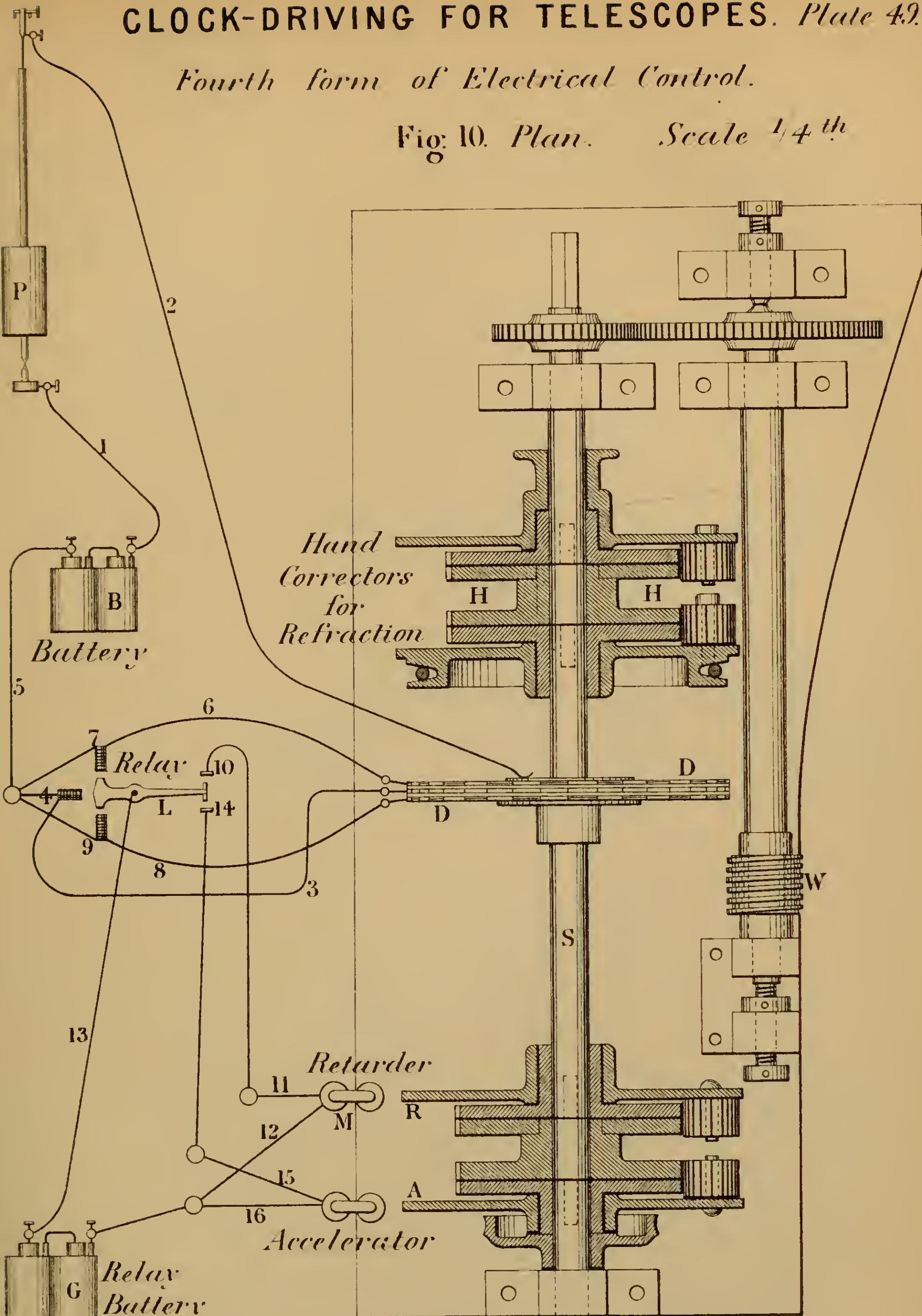
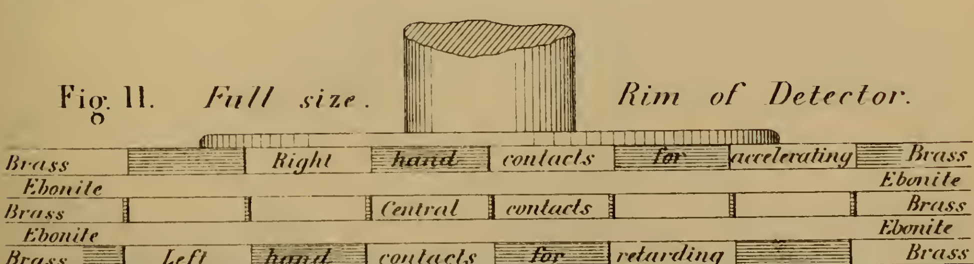


Fig. 11. Full size. Rim of Detector.



CLOCK-DRIVING FOR TELESCOPES.

Fourth form of Electrical Control.

Fig. 12. *Plan of Vibrating Lever and Magnets. Scale $^2/_3$rds.*

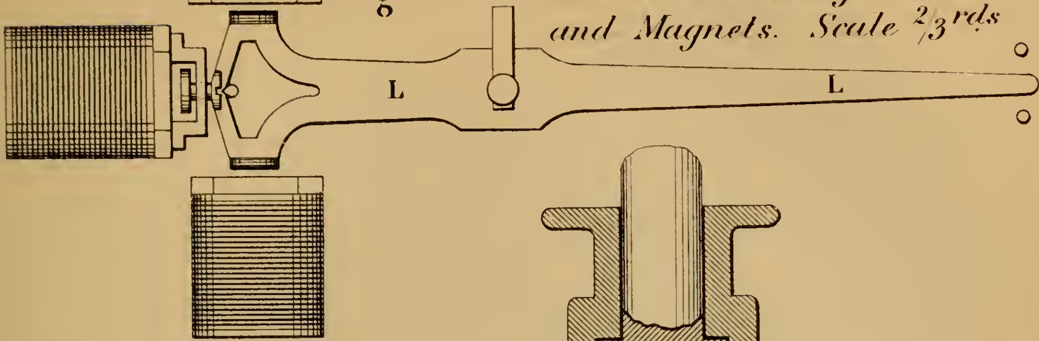


Fig. 13.
Hand Correctors for Refraction. Sectional Plan. Half full size.

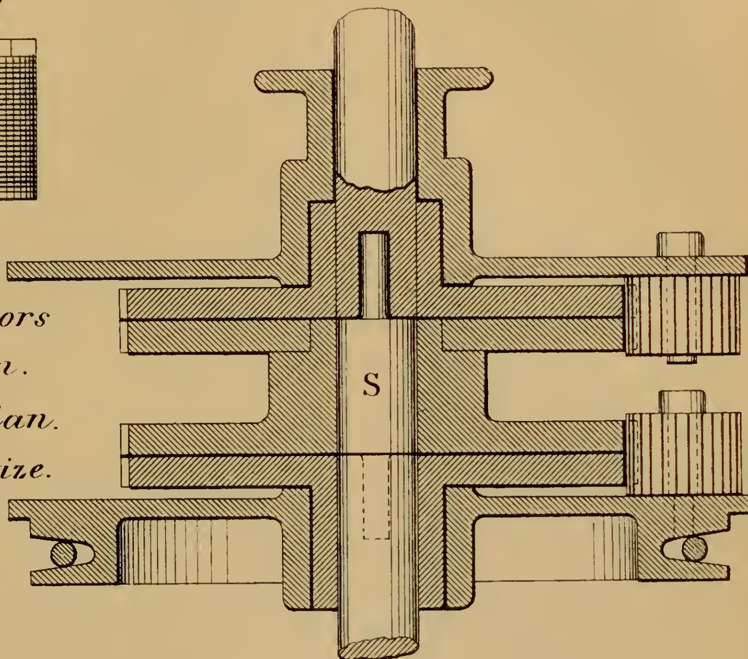
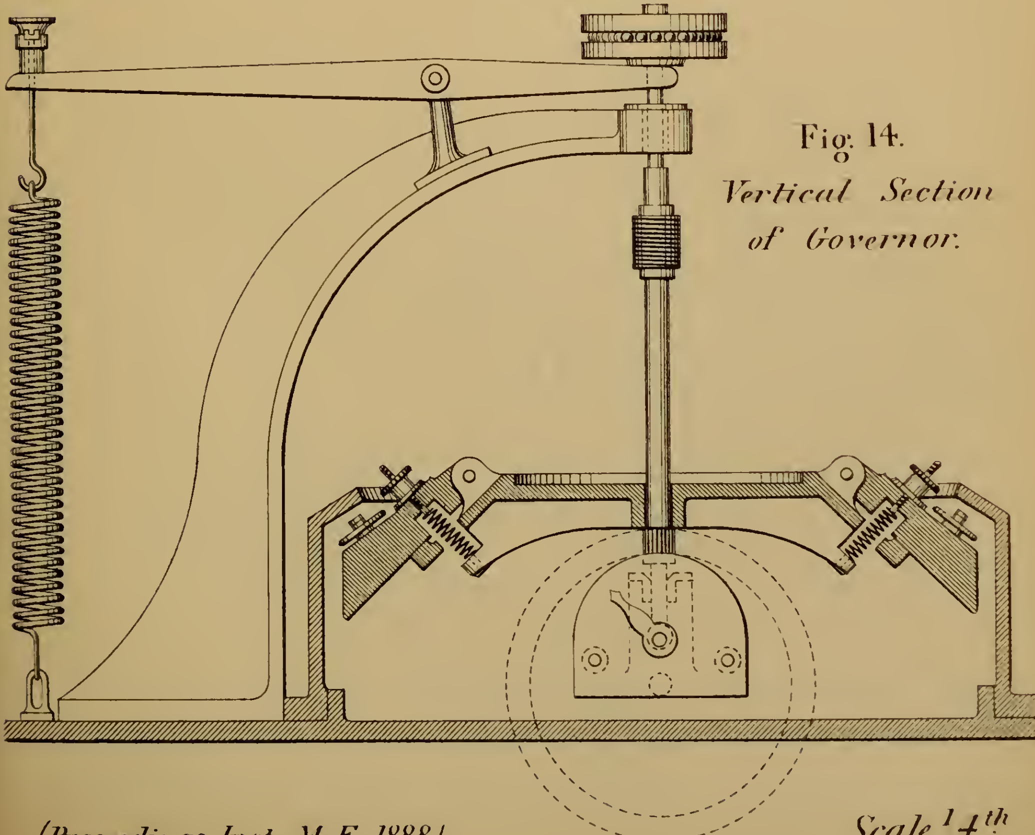


Fig. 14.
Vertical Section of Governor.



Scale $^1/_4$th.

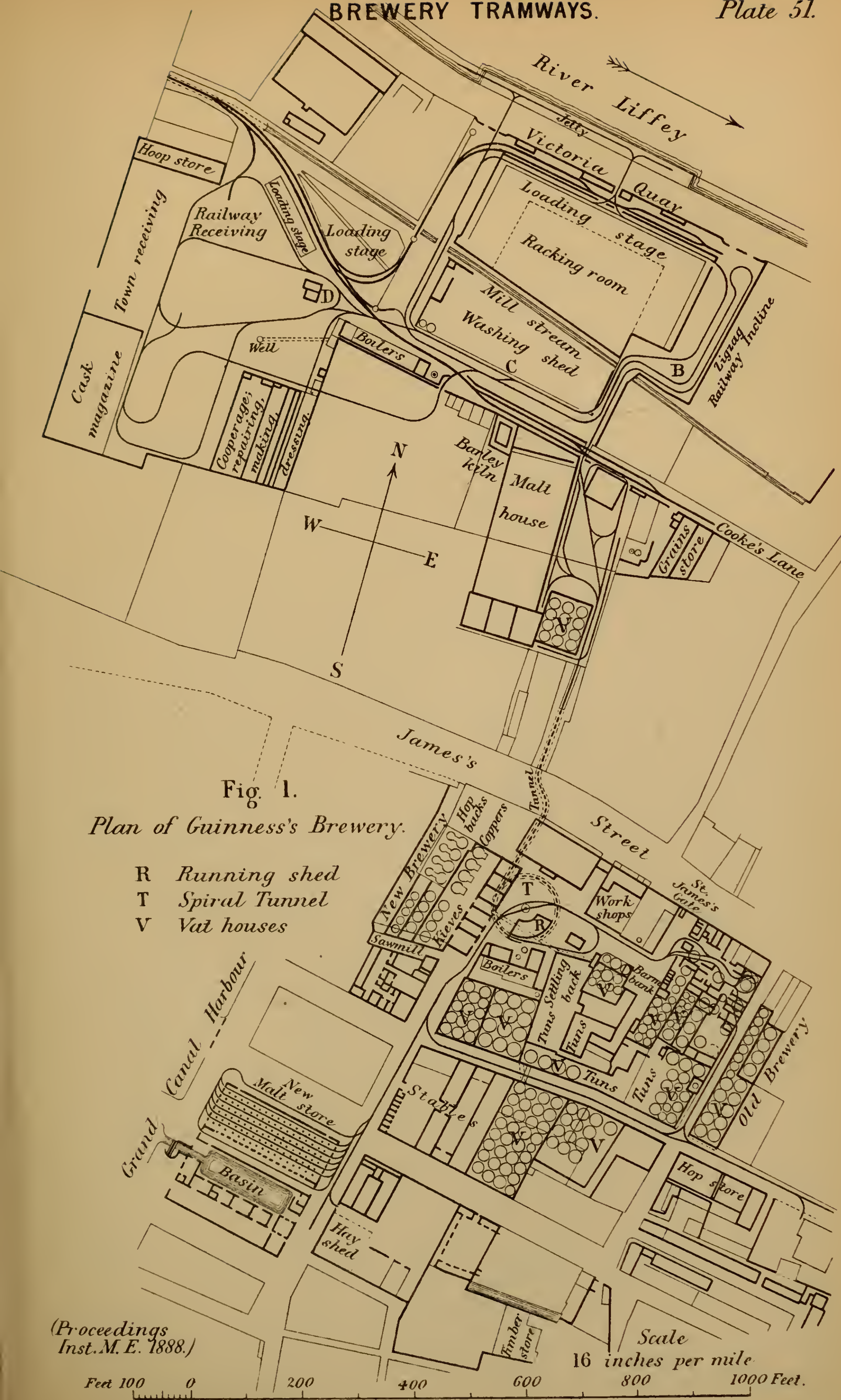


Fig. 1.

Plan of Guinness's Brewery.

R *Running shed*
T *Spiral Tunnel*
V *Vat houses*

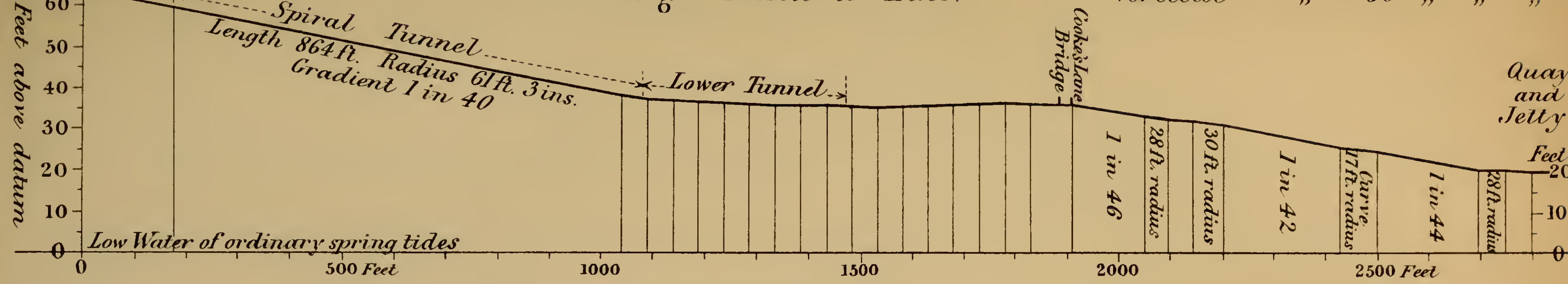
(Proceedings Inst. M. E. 1888.)

BREWERY TRAMWAYS.

Plate 52.

Horizontal Scale 400 feet per inch.
Vertical " 50 " " "

Fig. 2. *Profile of Line.*



Signals.

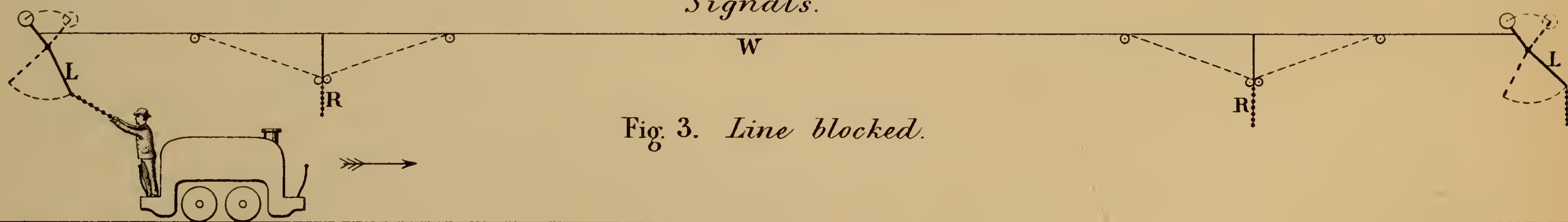


Fig. 3. *Line blocked.*

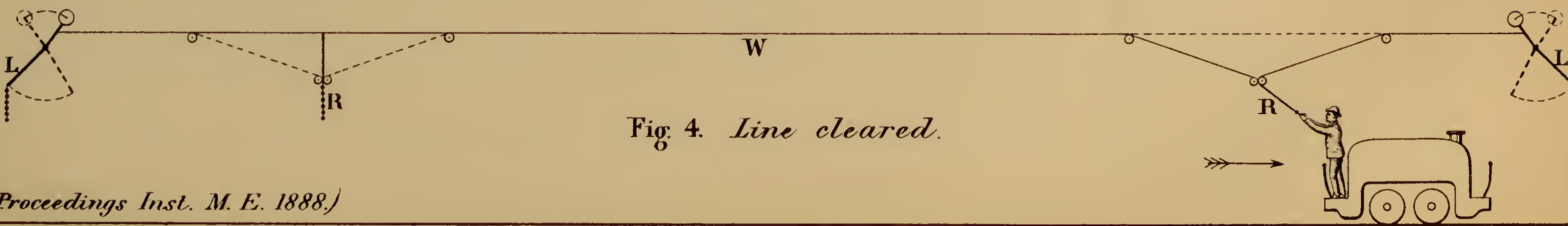
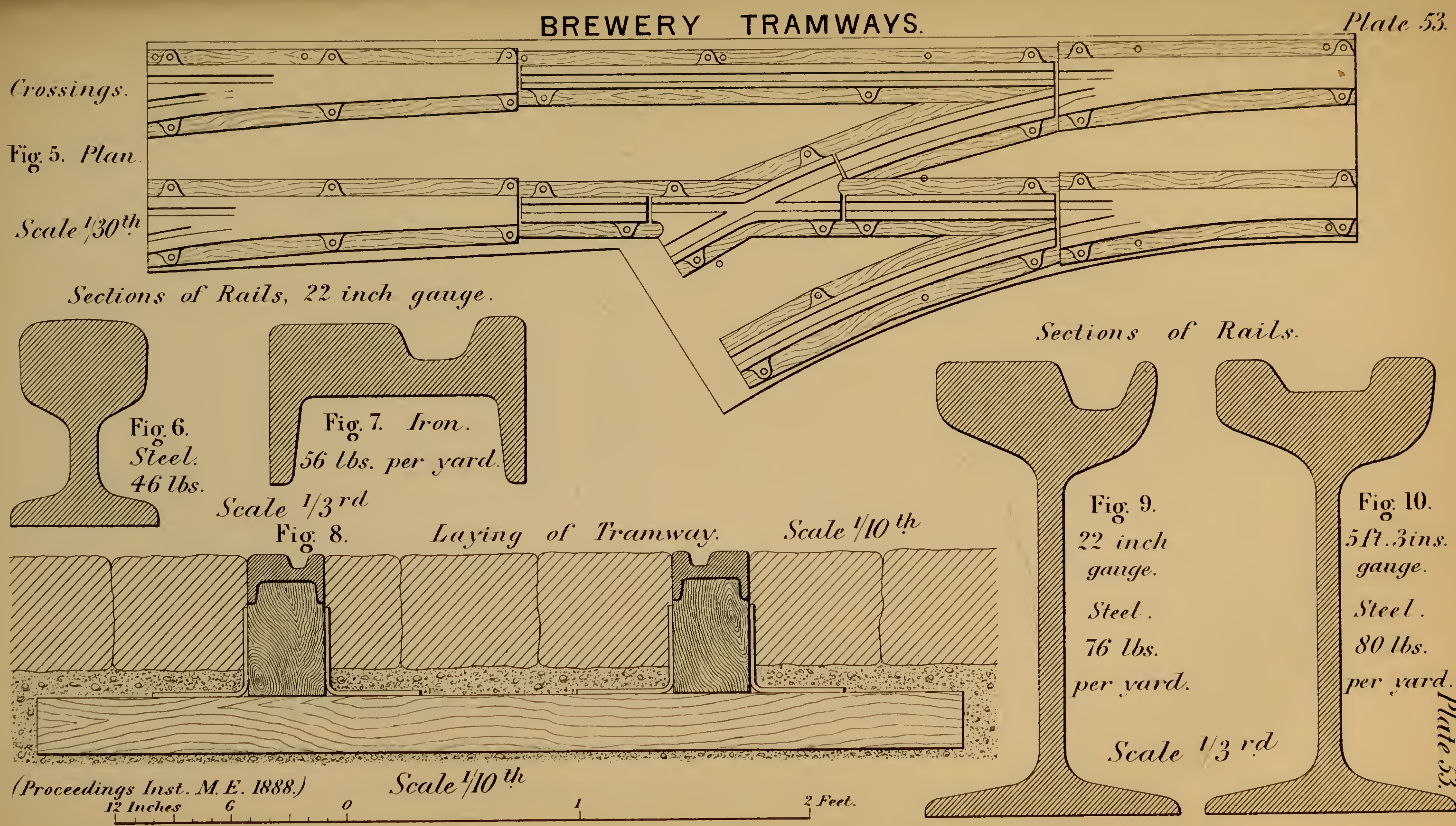


Fig. 4. *Line cleared.*

(Proceedings Inst. M. E. 1888.)

Plate 52.


BREWERY TRAMWAYS.
Plate 53.
Crossings.
Fig. 5. Plan.
Scale 1/30th.
Sections of Rails, 22 inch gauge.
Fig. 6. Steel. 46 lbs.
Fig. 7. Iron. 56 lbs. per yard.
Scale 1/3rd
Fig. 8. Laying of Tramway. Scale 1/10th.
Sections of Rails.
Fig. 9. 22 inch gauge. Steel. 76 lbs. per yard.
Fig. 10. 5 ft. 3 ins. gauge. Steel. 80 lbs. per yard.
Scale 1/3rd
Plate 53.
(Proceedings Inst. M.E. 1888.)
Scale 1/10th
12 Inches 6 0 1 2 Feet.

Locomotives.

Fig. 11.

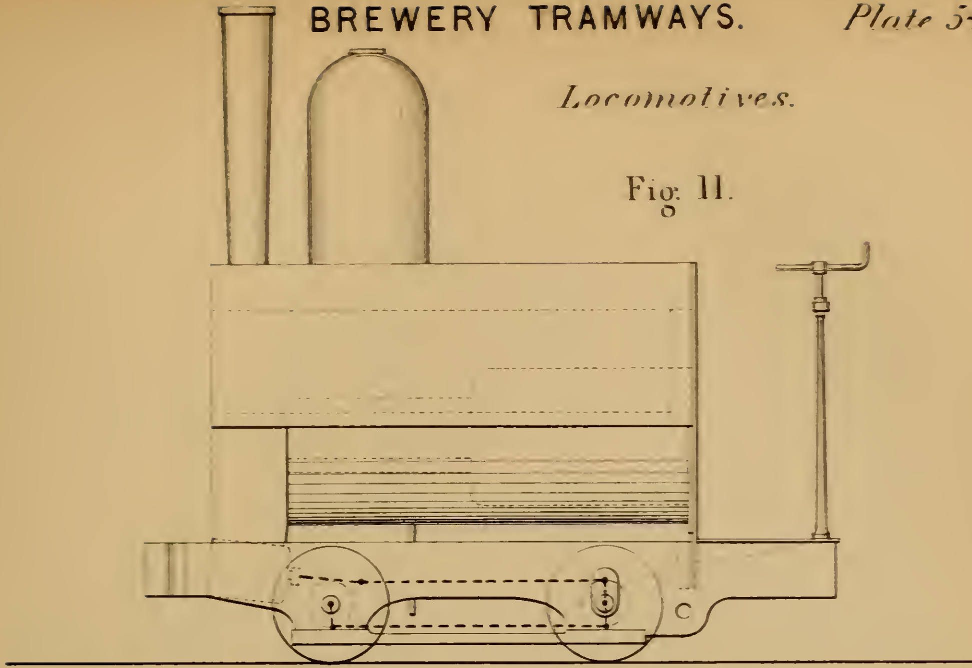


Fig. 12.

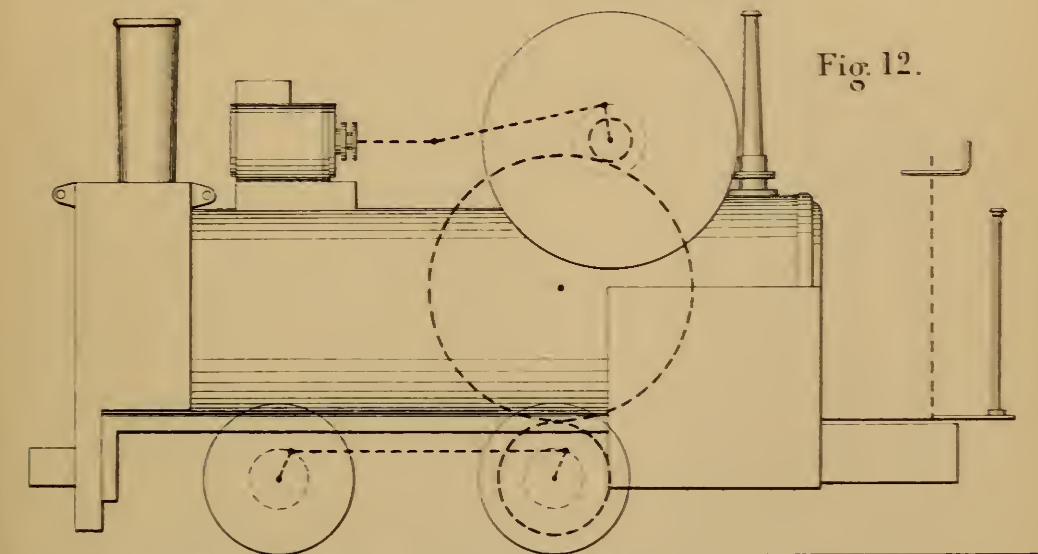
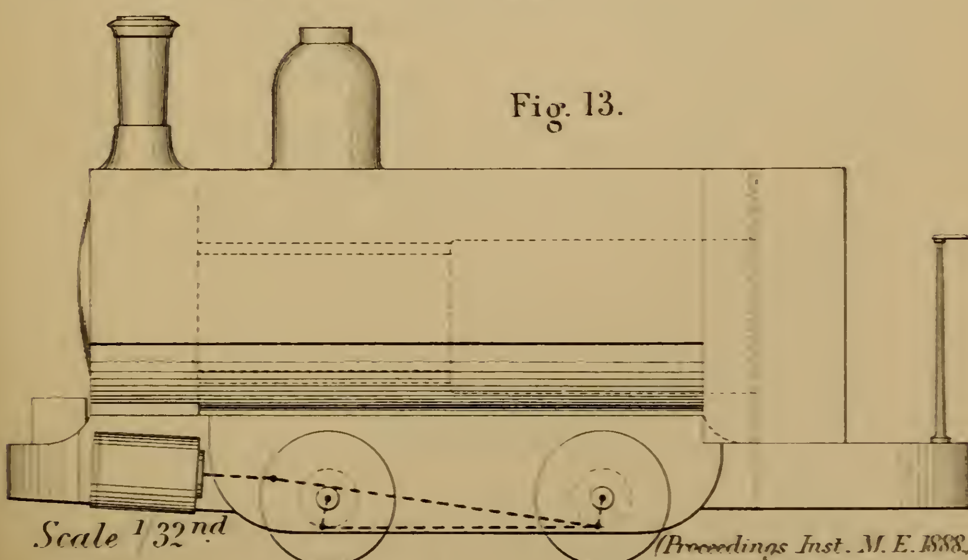


Fig. 13.



Scale 1/32nd.

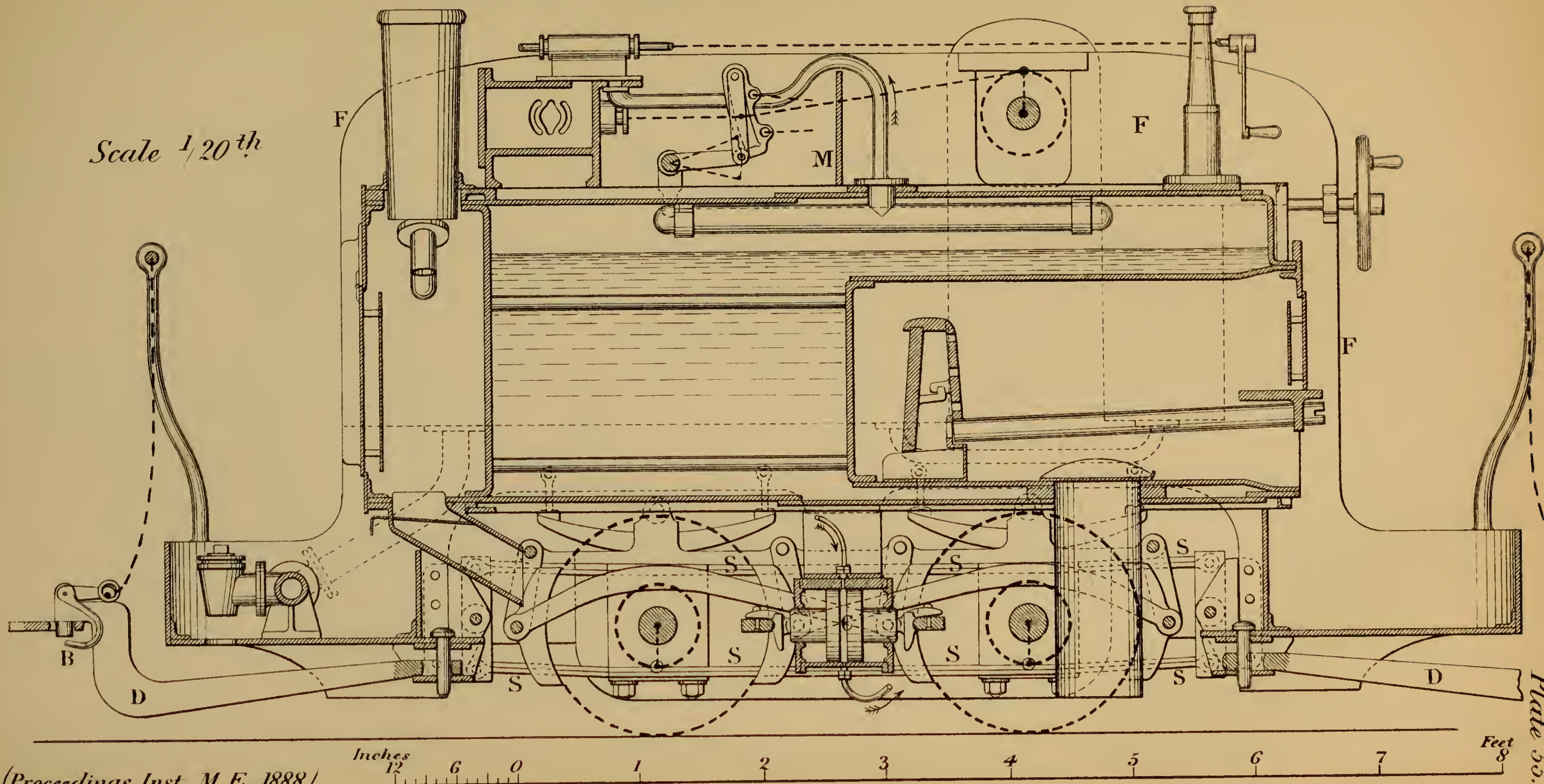
(Proceedings Inst. M. E. 1888.)

12 Ins. 0 1 2 3 4 5 6 7 8 9 Feet 10

BREWERY TRAMWAYS.

Locomotive. Fig. 14. Longitudinal Section

Scale 1/20th.



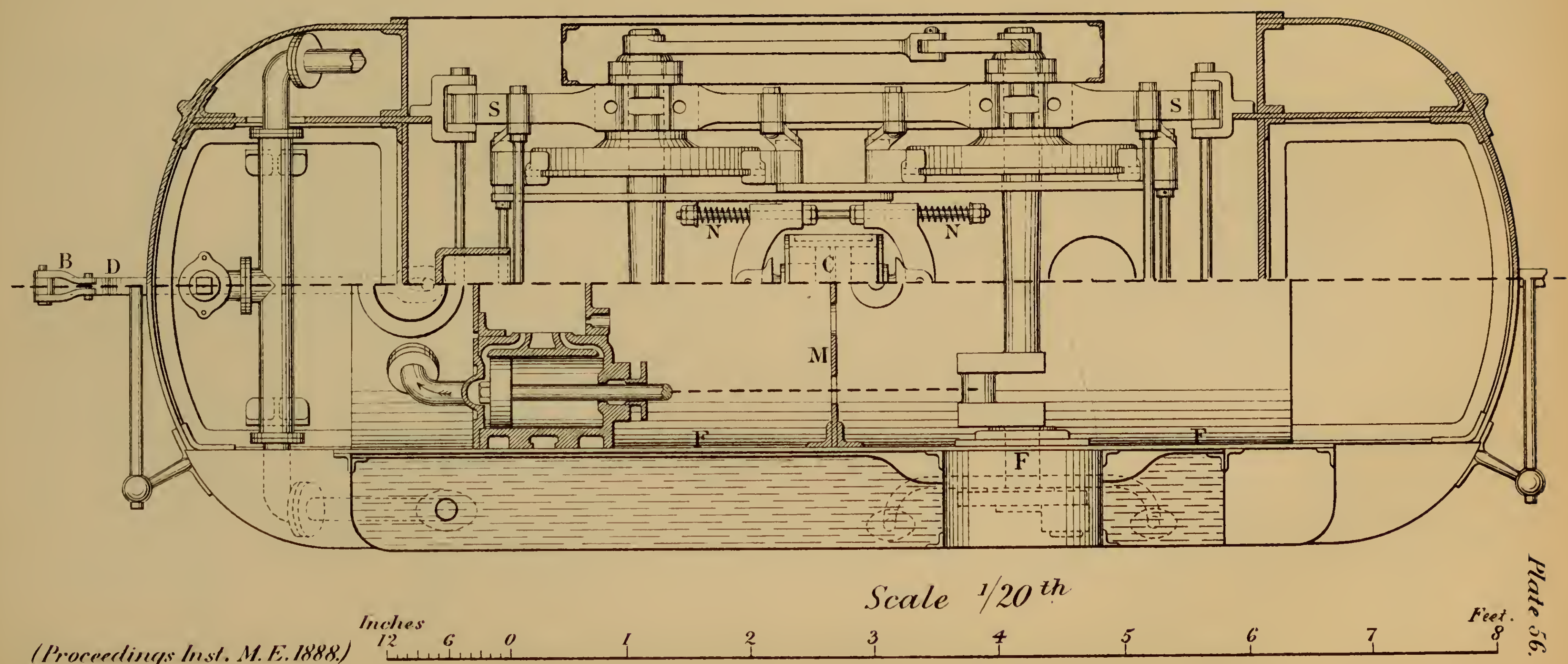
(Proceedings Inst. M. E. 1888.)

Plate 55.

BREWERY TRAMWAYS.

Locomotive.

Fig. 15. *Plan.*



(Proceedings Inst. M. E. 1888.)

Plate 56.

BREWERY TRAMWAYS.

Locomotive.

Cross Sections.

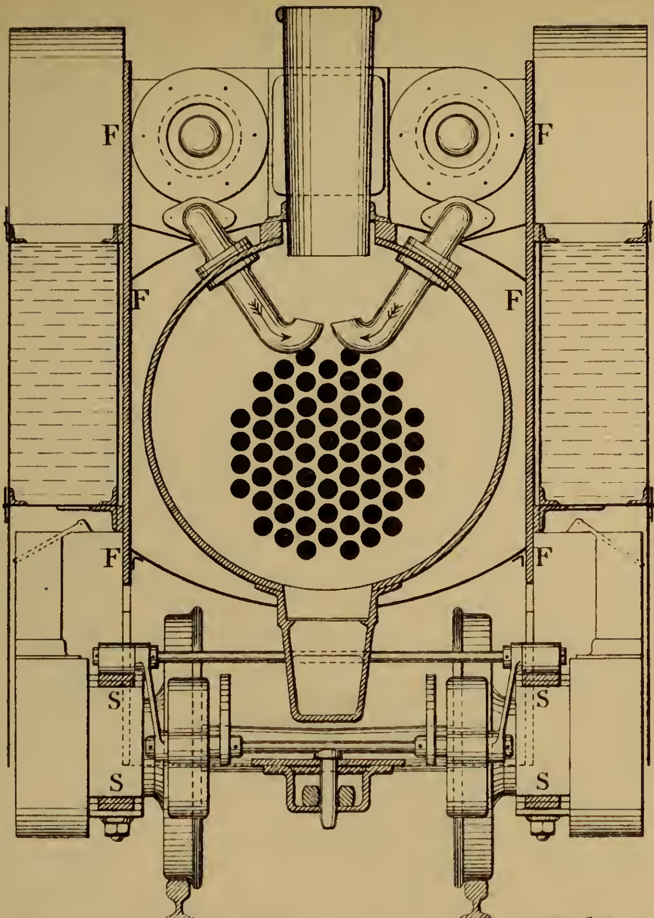


Fig. 16.

Through Smokebox, looking backwards.

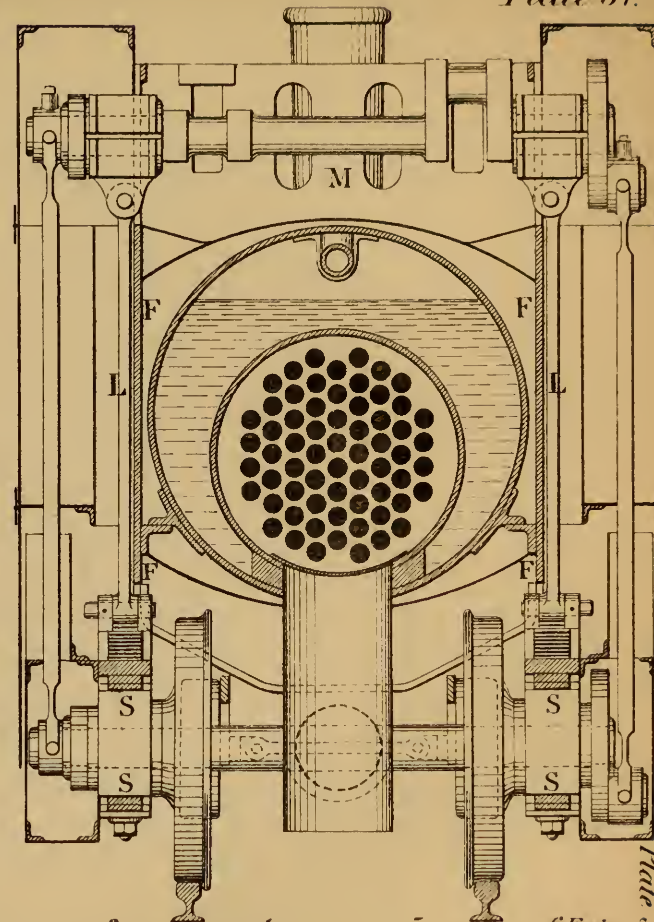


Fig. 17.

Through Firebox, looking forwards.

Scale 1/20th

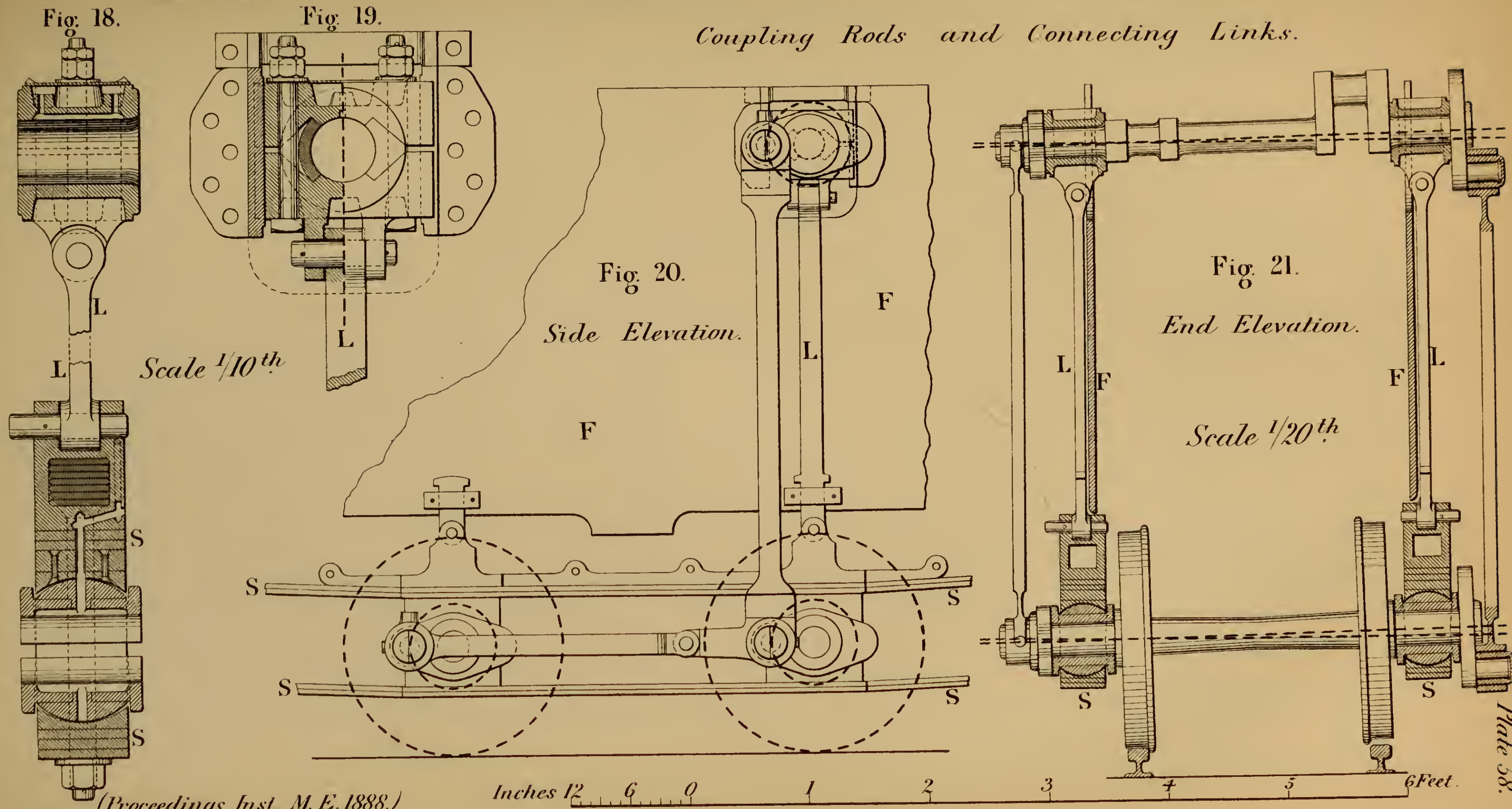
Inches 12 6 0 1 2 3 4 5 6 Feet.

Plate 57.

BREWERY TRAMWAYS.

Axle-boxes.

Coupling Rods and Connecting Links.



(Proceedings Inst. M. E. 1888.)

BREWERY TRAMWAYS.

Tip Wagon.

Fig: 22. *End Elevation.*

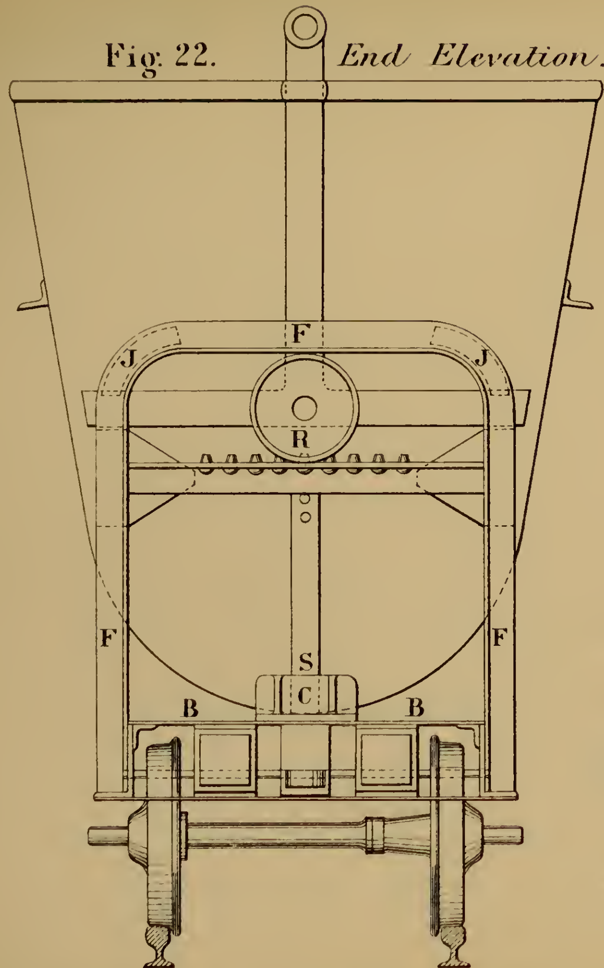
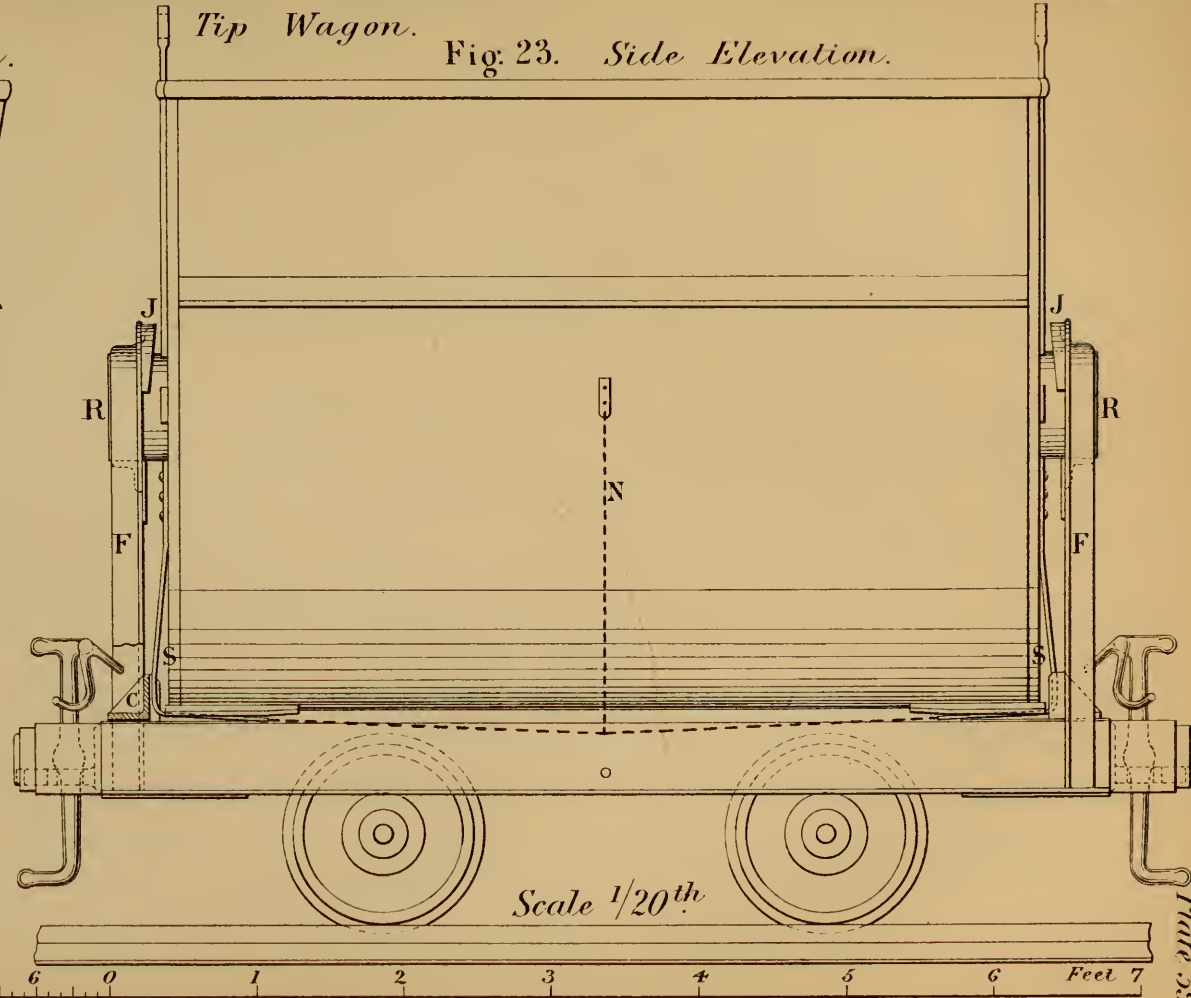


Fig: 23. *Side Elevation.*



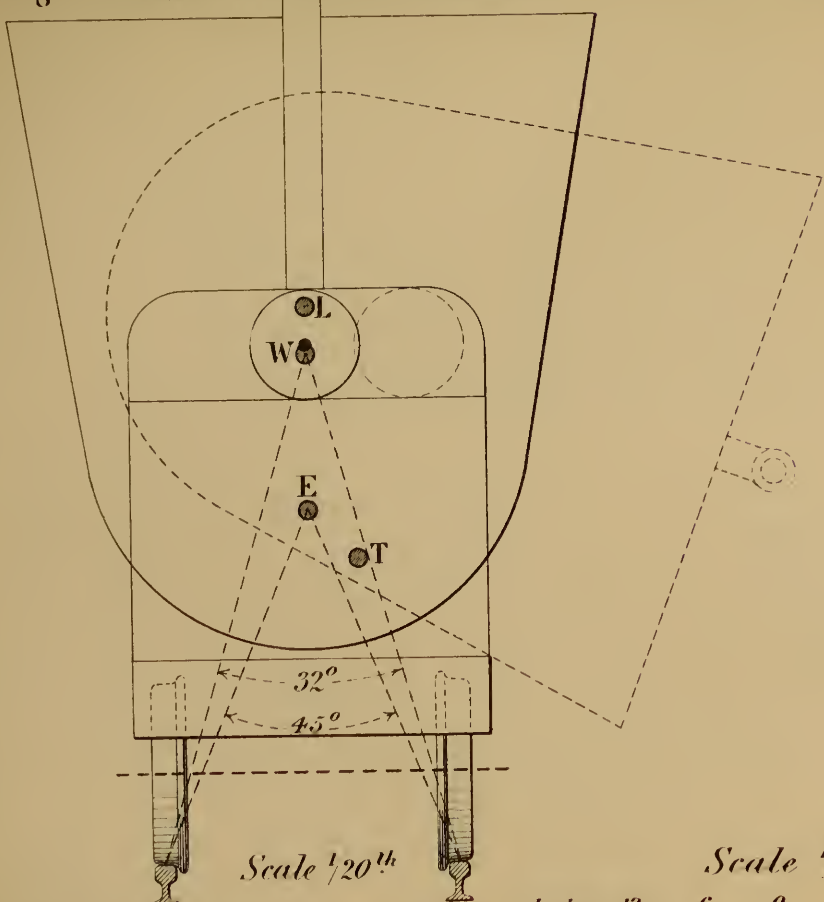
(Proceedings Inst. M. E. 1888.)

Plate 59.

BREWERY TRAMWAYS.

Plate 60.

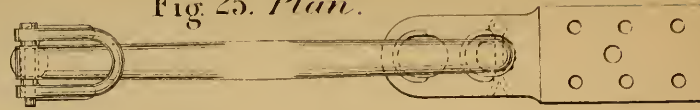
Fig. 24. *Diagram of Tipping.*



Scale 1/20th.

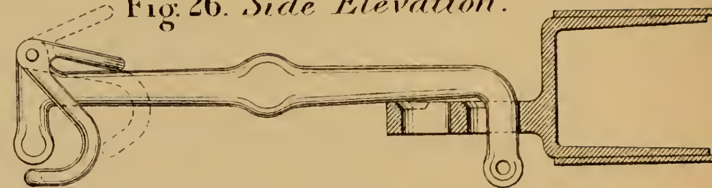
Tip Wagon.

Fig. 25. *Plan.*



Coupling Bar.

Fig. 26. *Side Elevation.*



Scale 1/10th.

End Roller.

Fig. 27. *Sectional Plan.*

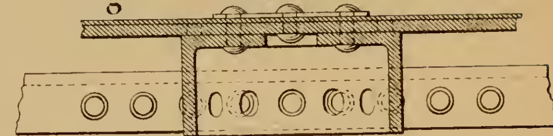
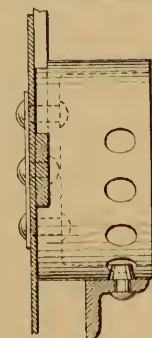


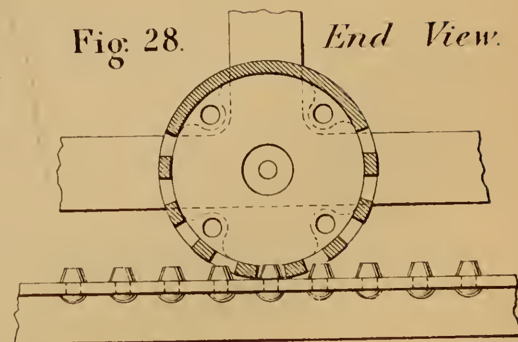
Fig. 29.

Side Elevation.



Scale 1/10th.

Fig. 28. *End View.*



Scale 1/20th.

Inches 12 6 0 1 2 3 4 5 6 *Feet.*

(Proceedings Inst. M. E. 1888.)

Plate 60.

BREWERY TRAMWAYS.

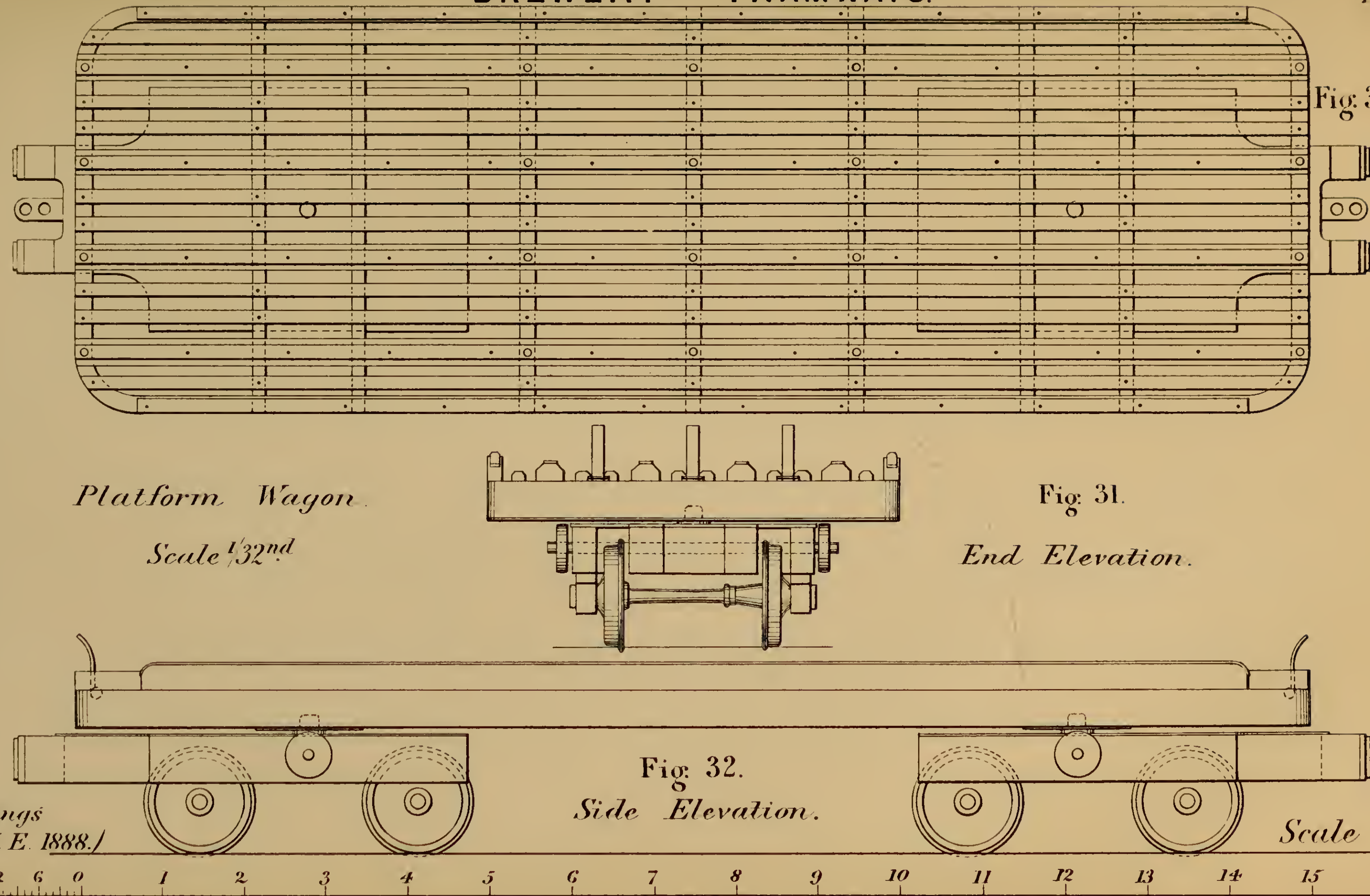


Fig. 30. Plan.

Platform Wagon.

Scale 1/32nd.

Fig. 31.

End Elevation.

Fig. 32.

Side Elevation.

Scale 1/32nd.

(Proceedings Inst. M. E. 1888.)

Plate 61.

Bogey of Platform Wagon.

Fig. 33. *End Elevation.*

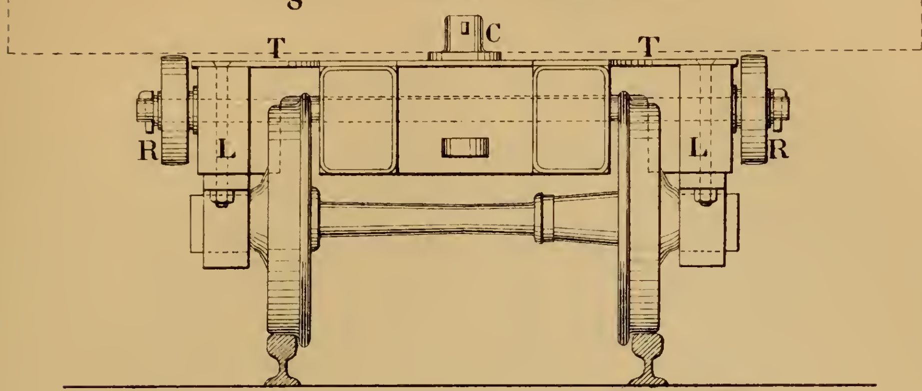


Fig. 34. *Plan.*

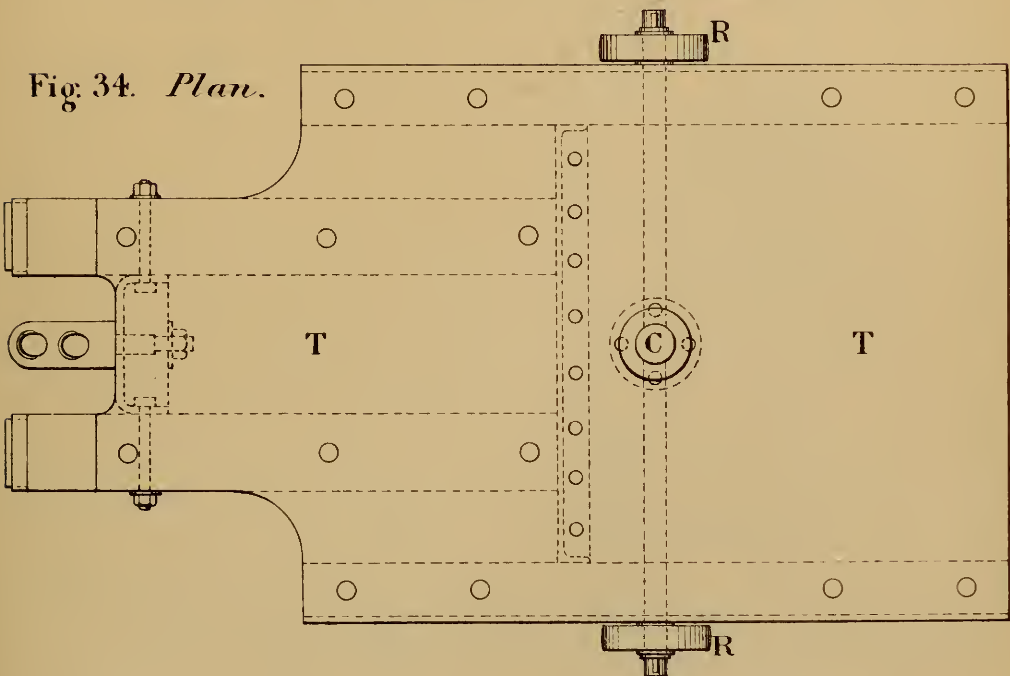
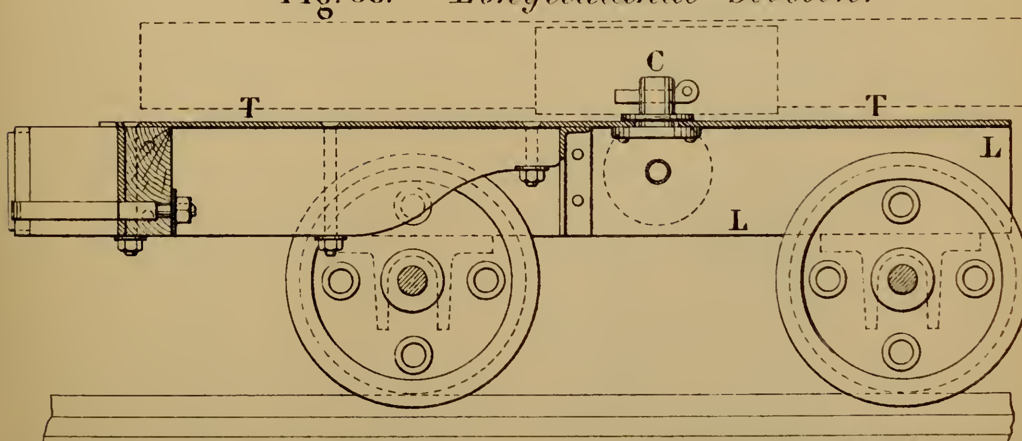


Fig. 35. *Longitudinal Section.*



(Proceedings Inst. M. E. 1888.)

Scale 1/16th

Ins. 12 6 0 1 2 3 4 *Feet.*

BREWERY TRAMWAYS.

Haulage Truck.

Fig. 36. *Transverse Section.*

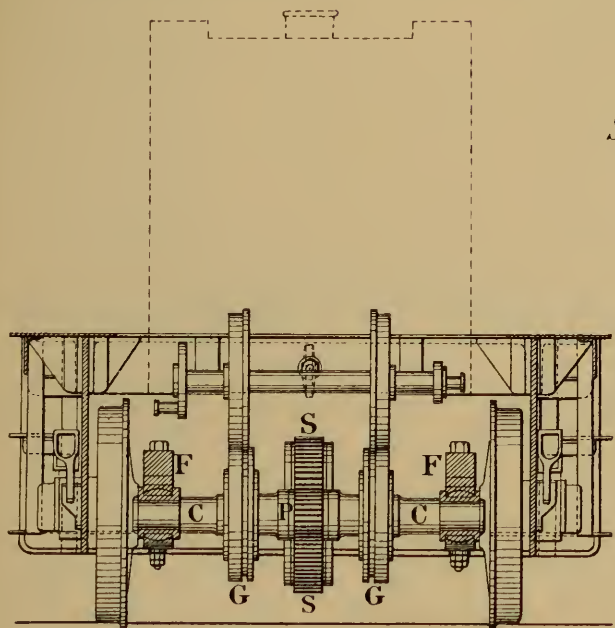
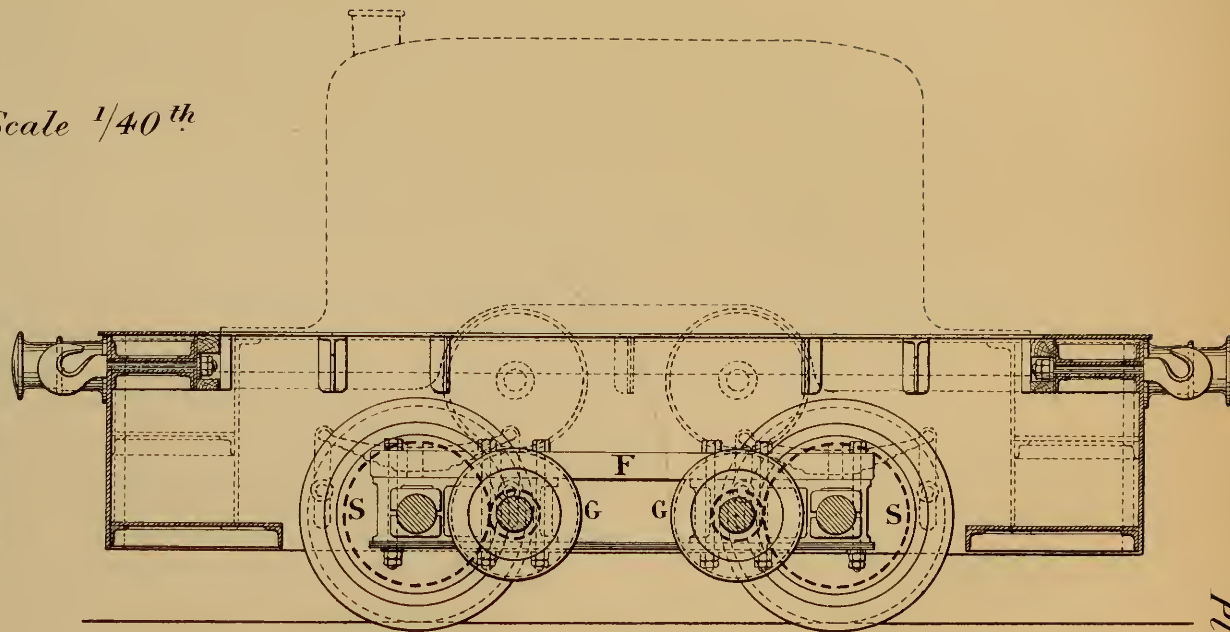


Fig. 37. *Longitudinal Section.*



Scale 1/40th.

Scale 1/40th.

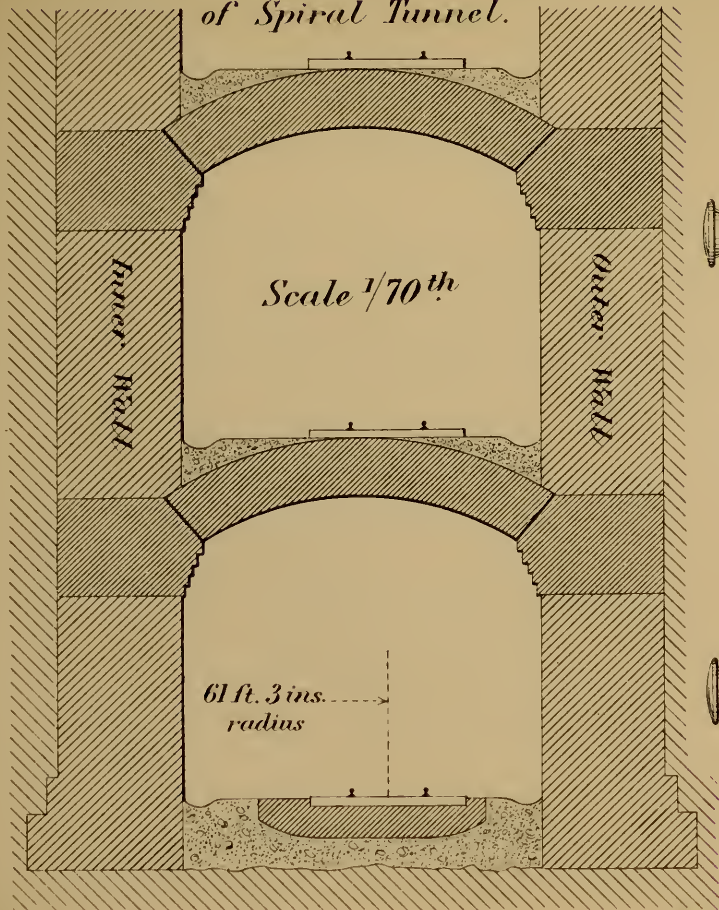
Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 Feet.

(Proceedings Inst. M. E. 1888.)

Plate 63.

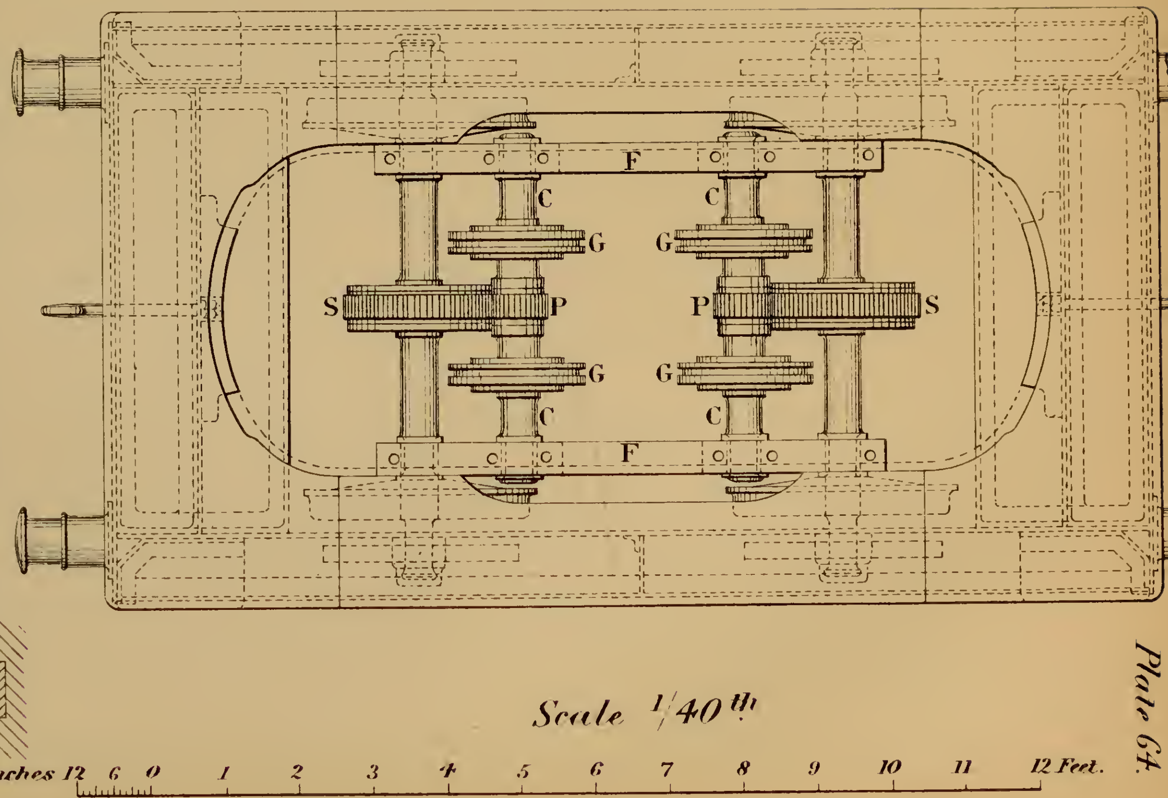
BREWERY TRAMWAYS.

Fig. 39. *Transverse Section of Spiral Tunnel.*



Haulage Truck.

Fig. 38. *Plan.*

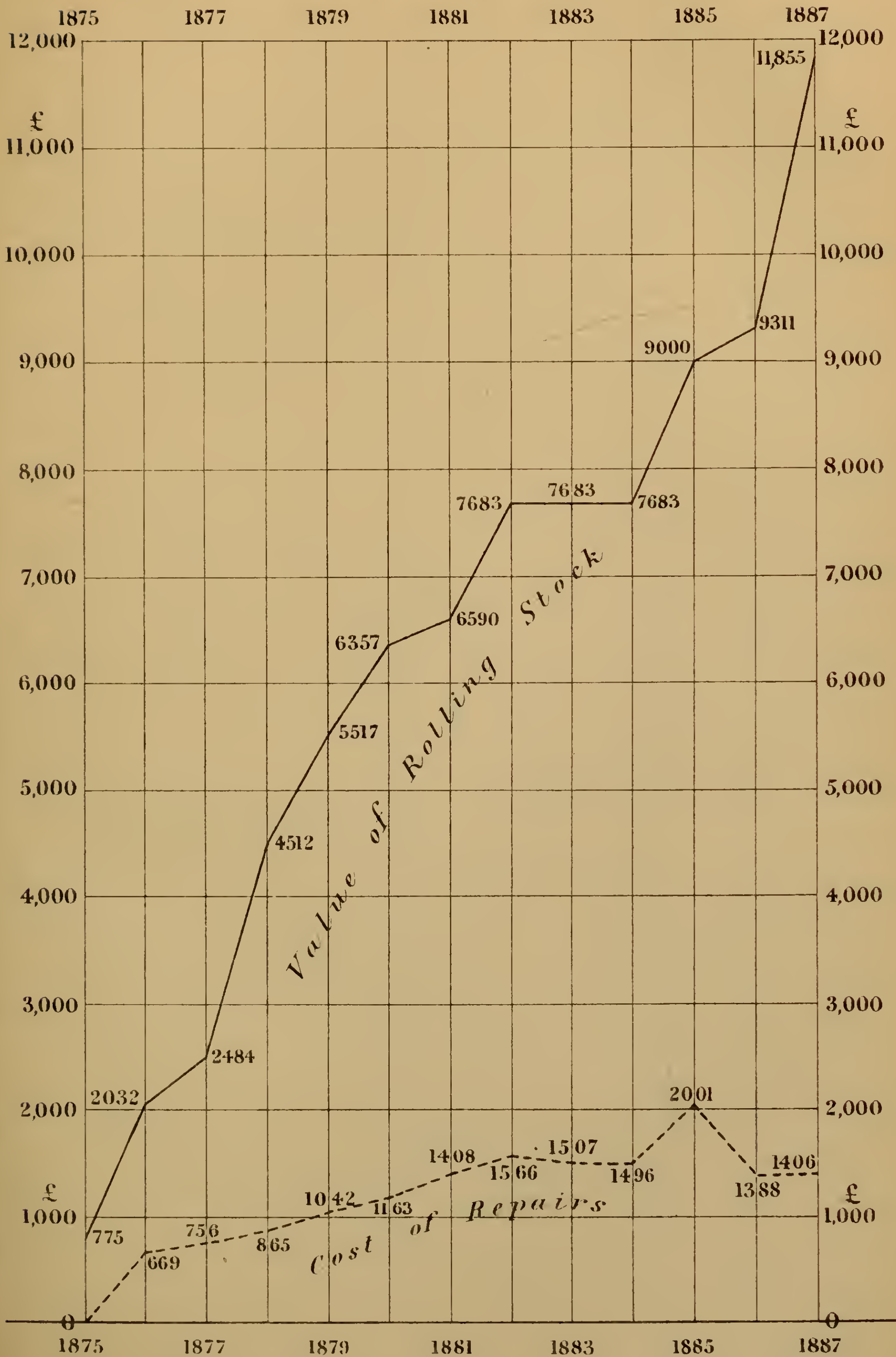


(Proceedings Inst. M. E. 1888.)

Plate 64.

BREWERY TRAMWAYS. *Plate 65.*

Fig: 40. *Value of Rolling Stock* ——————
and Cost of Repairs - - - - - - -



(Proceedings Inst. M. E. 1888.)

HORWICH ROLLING STOCK.

Locomotive for 18 inch gauge.

Scale 1/20th

Fig. 41. Longitudinal Section.

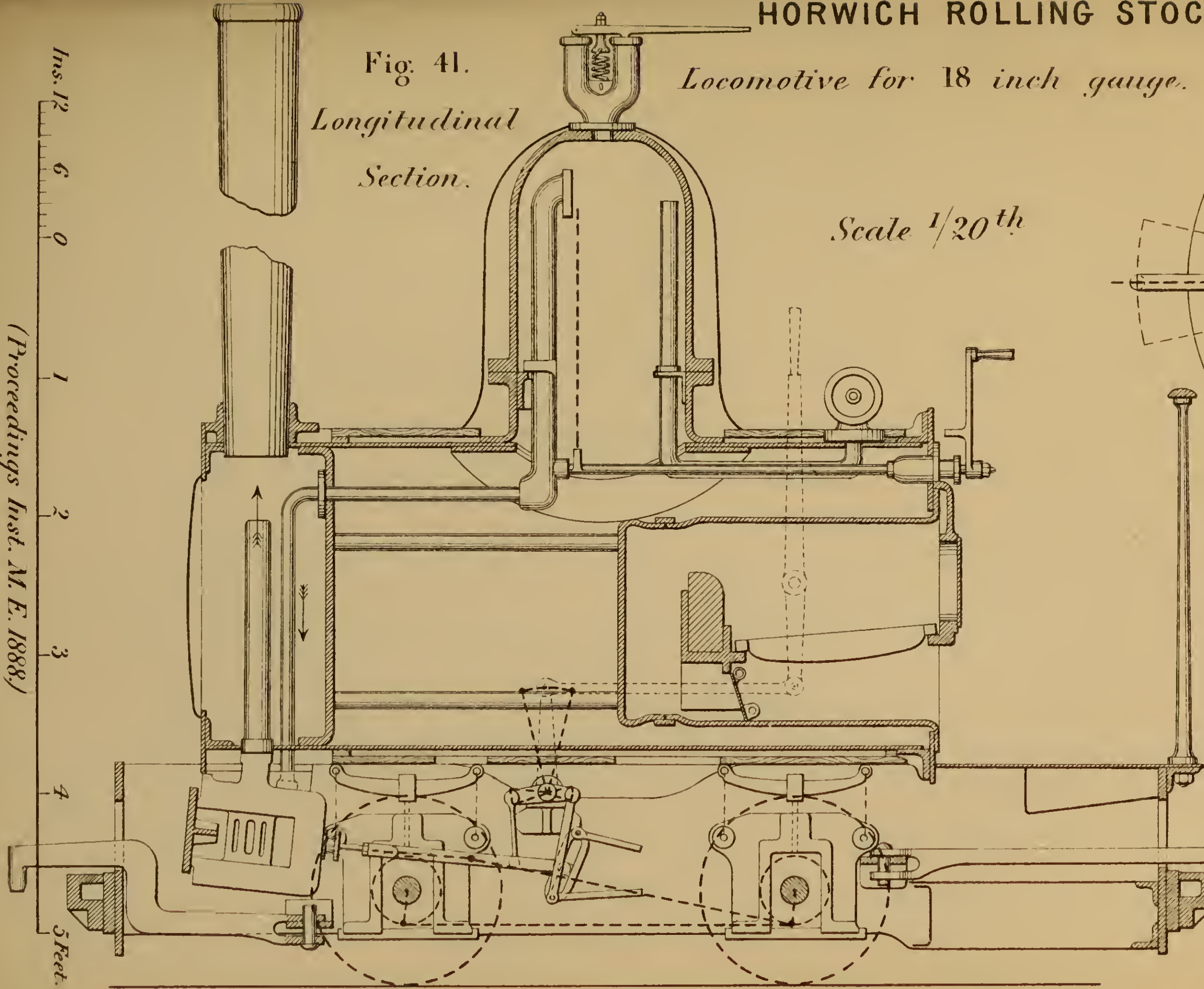


Fig. 42. Plan of Leading end.

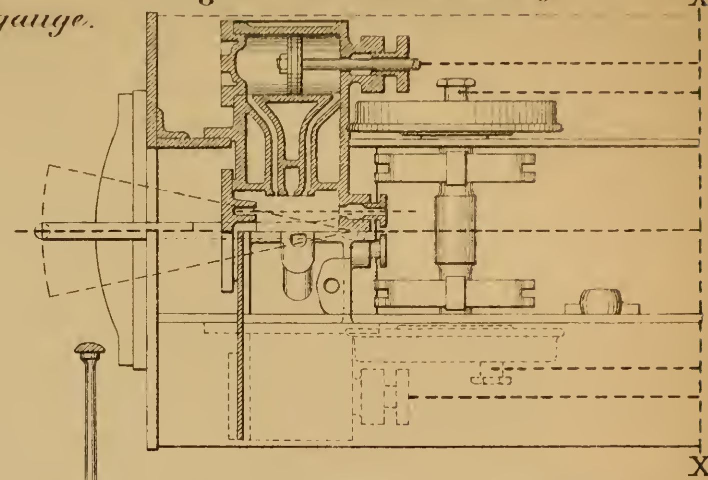


Fig. 43. Plan of Trailing end.

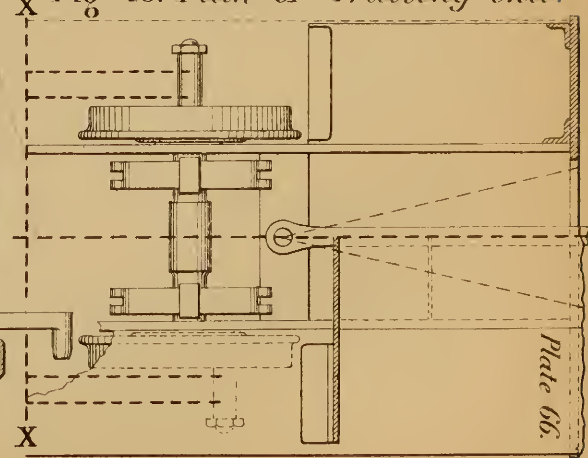
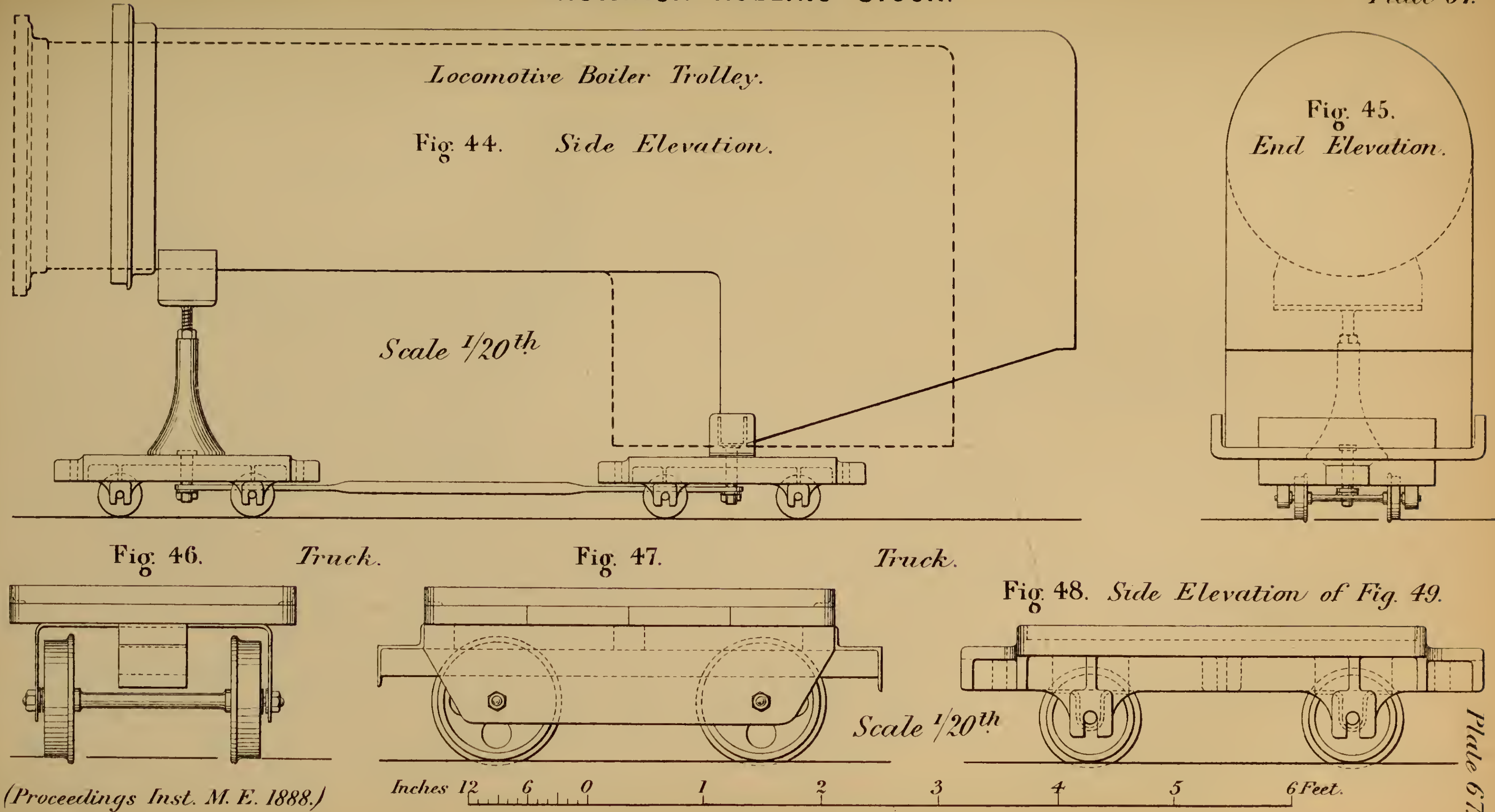


Plate 66.

HORWICH ROLLING STOCK.



(Proceedings Inst. M. E. 1888.)

HORWICH ROLLING STOCK.

Tip Truck.

Scale 1/20th.

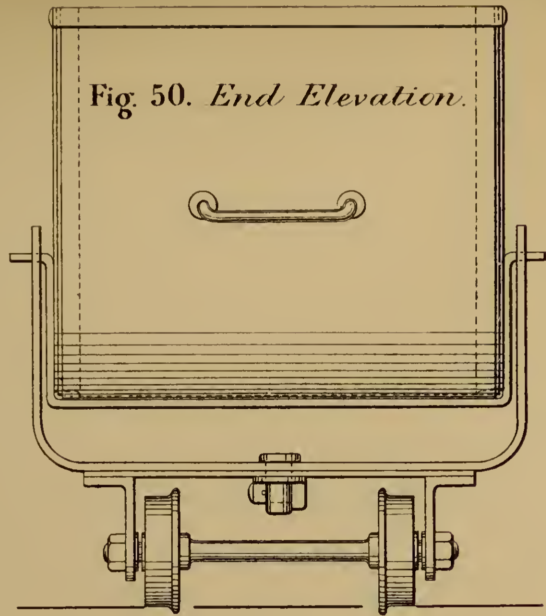


Fig. 50. *End Elevation.*

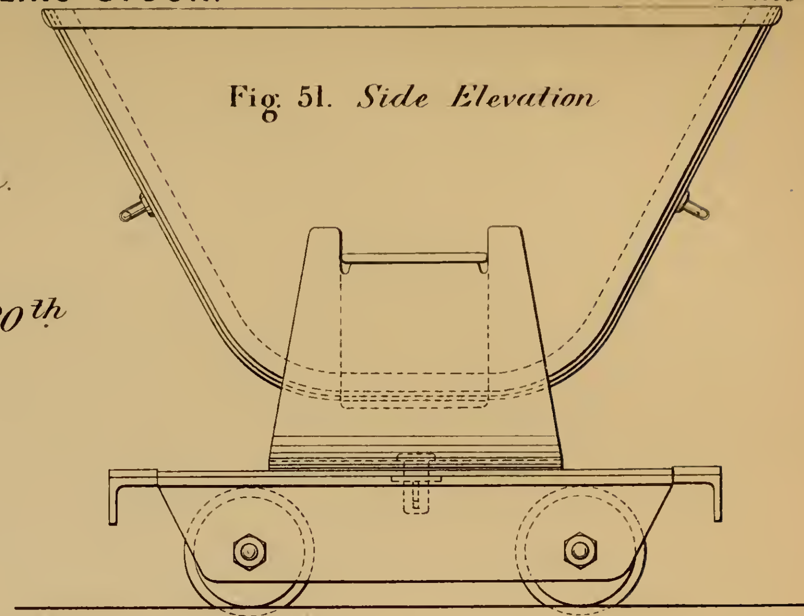


Fig. 51. *Side Elevation*

Truck.

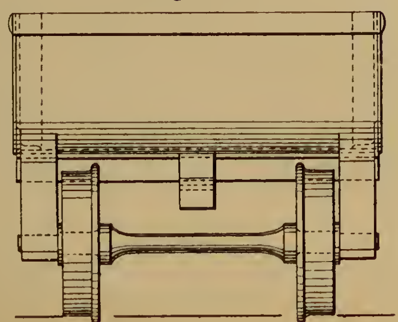


Fig. 52.

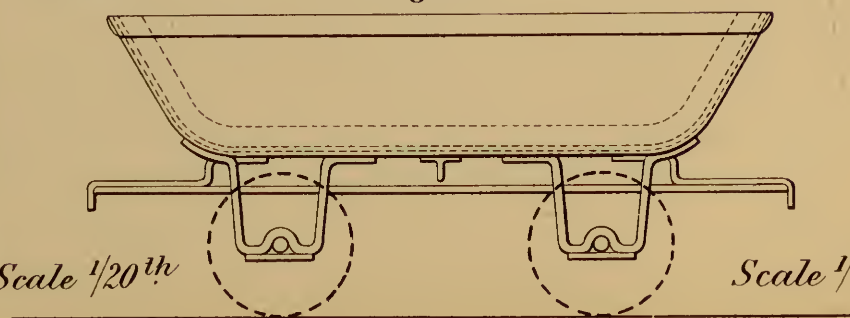


Fig. 53.

Scale 1/20th.

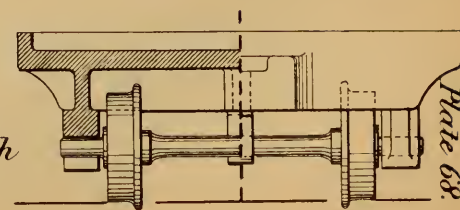


Fig. 49. *End Elevation of Fig. 48.*

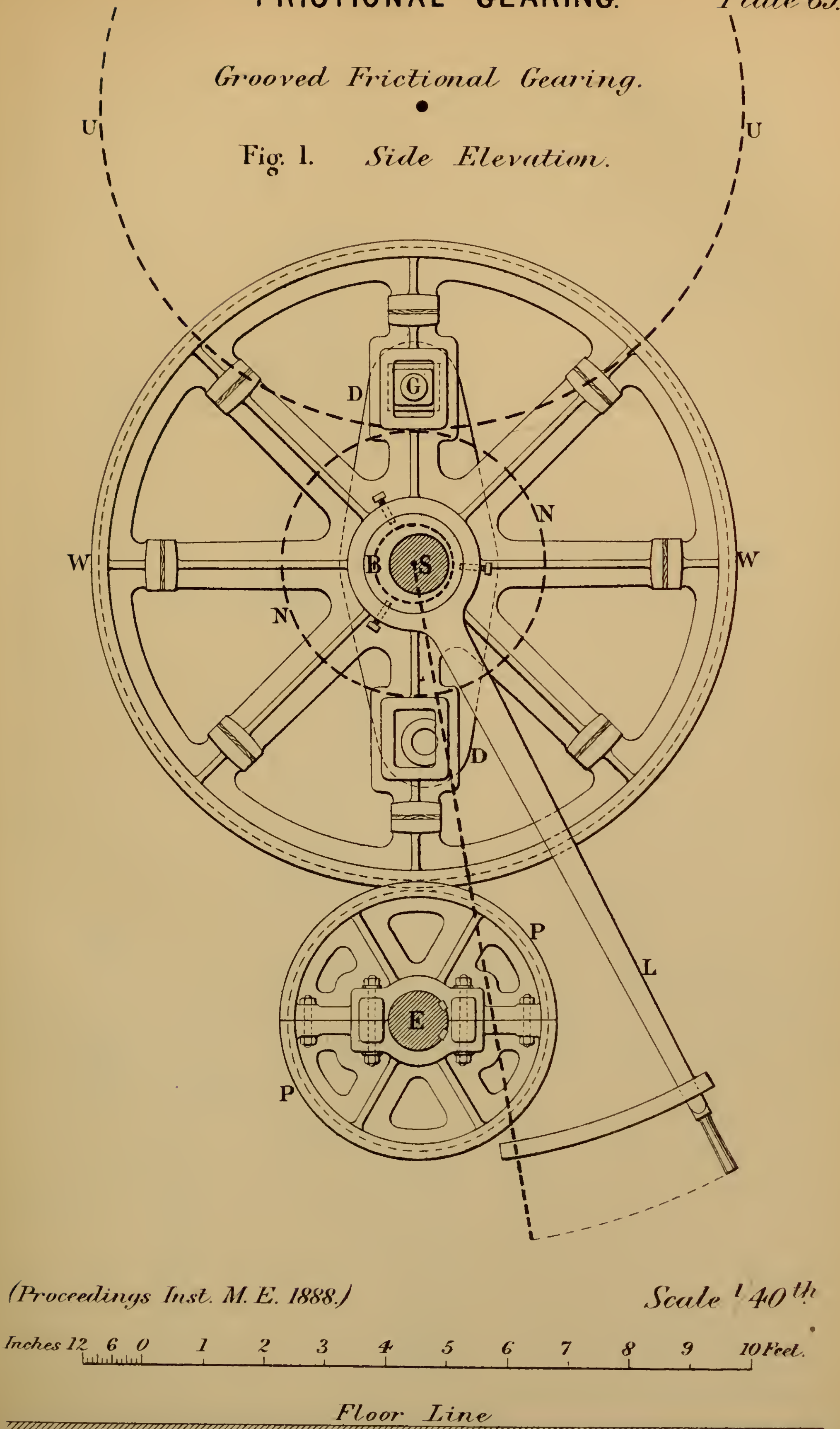
Scale 1/20th.

Plate 68.

(Proceedings Inst. M. E. 1888.)

Grooved Frictional Gearing.

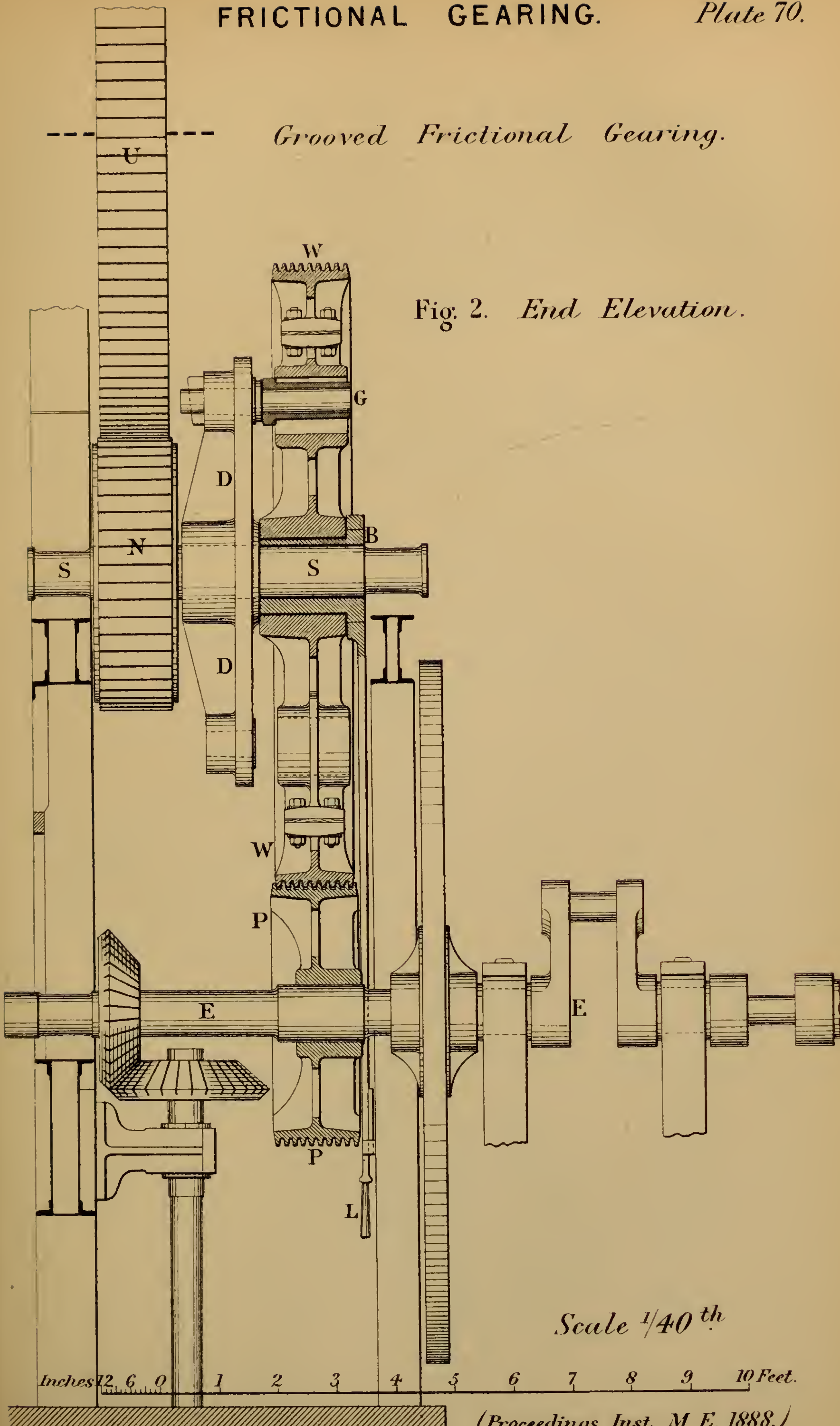
Fig. 1. *Side Elevation.*



(Proceedings Inst. M. E. 1888.) *Scale 1/40th*

Grooved Frictional Gearing.

Fig. 2. *End Elevation.*



Scale 1/40th.

Grooved Frictional Gearing.

Fig. 3. *Grooves when worn. Scale 1/4th*

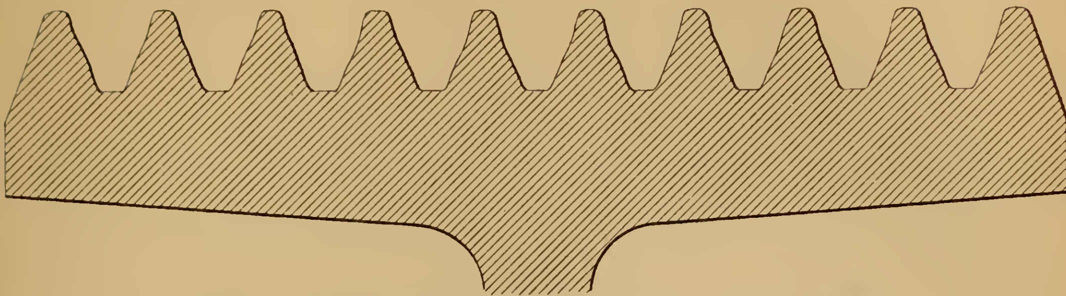
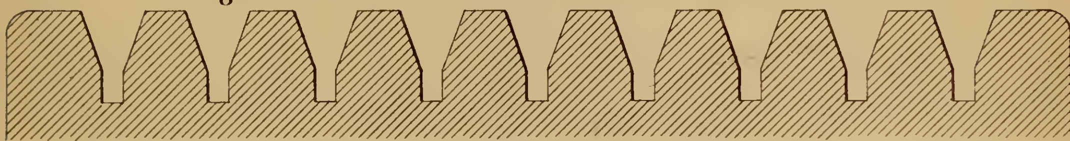


Fig. 4. *New form of Grooves. Scale 1/4th*



Spur Gearing with Brake-Wheels.

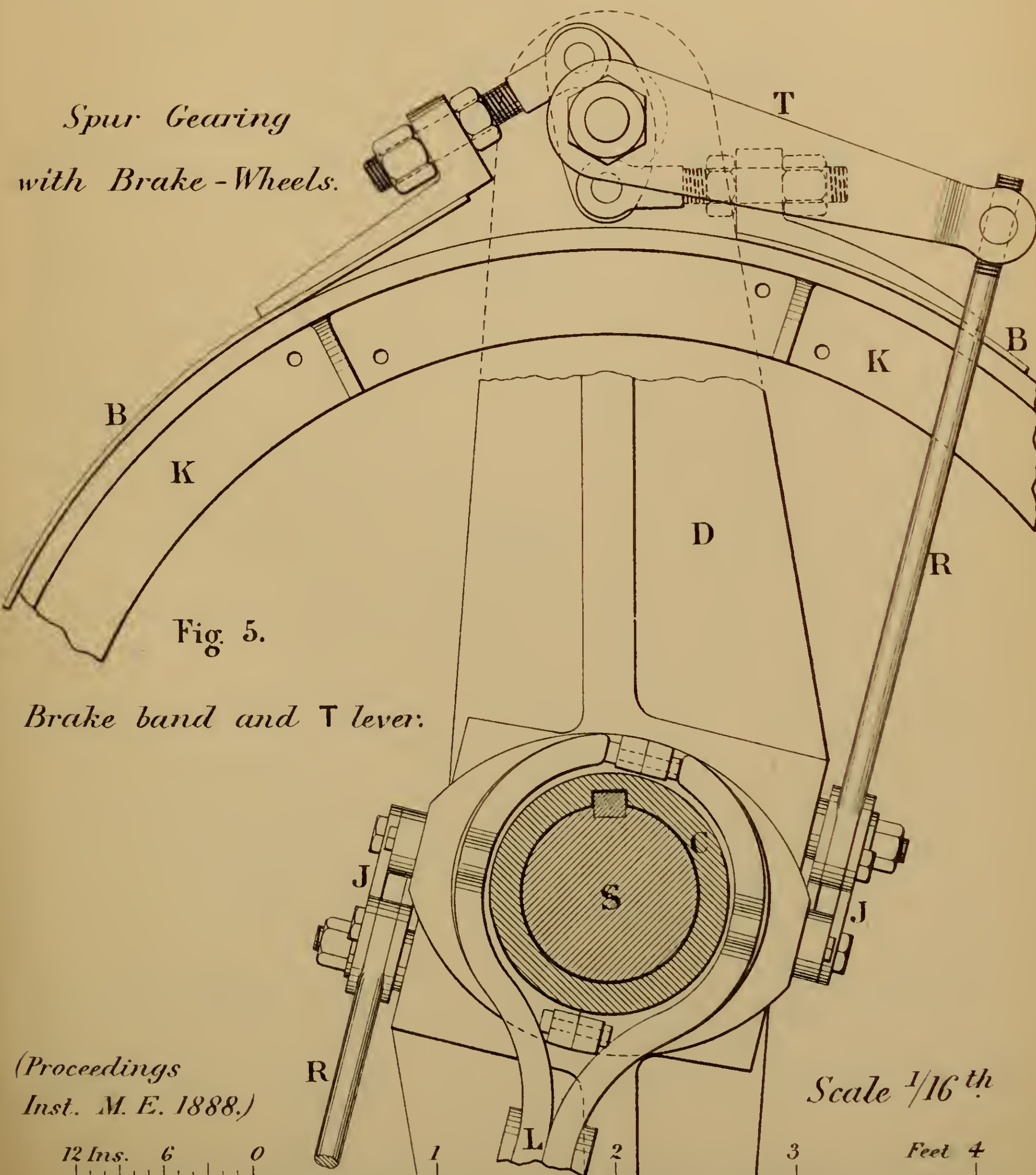
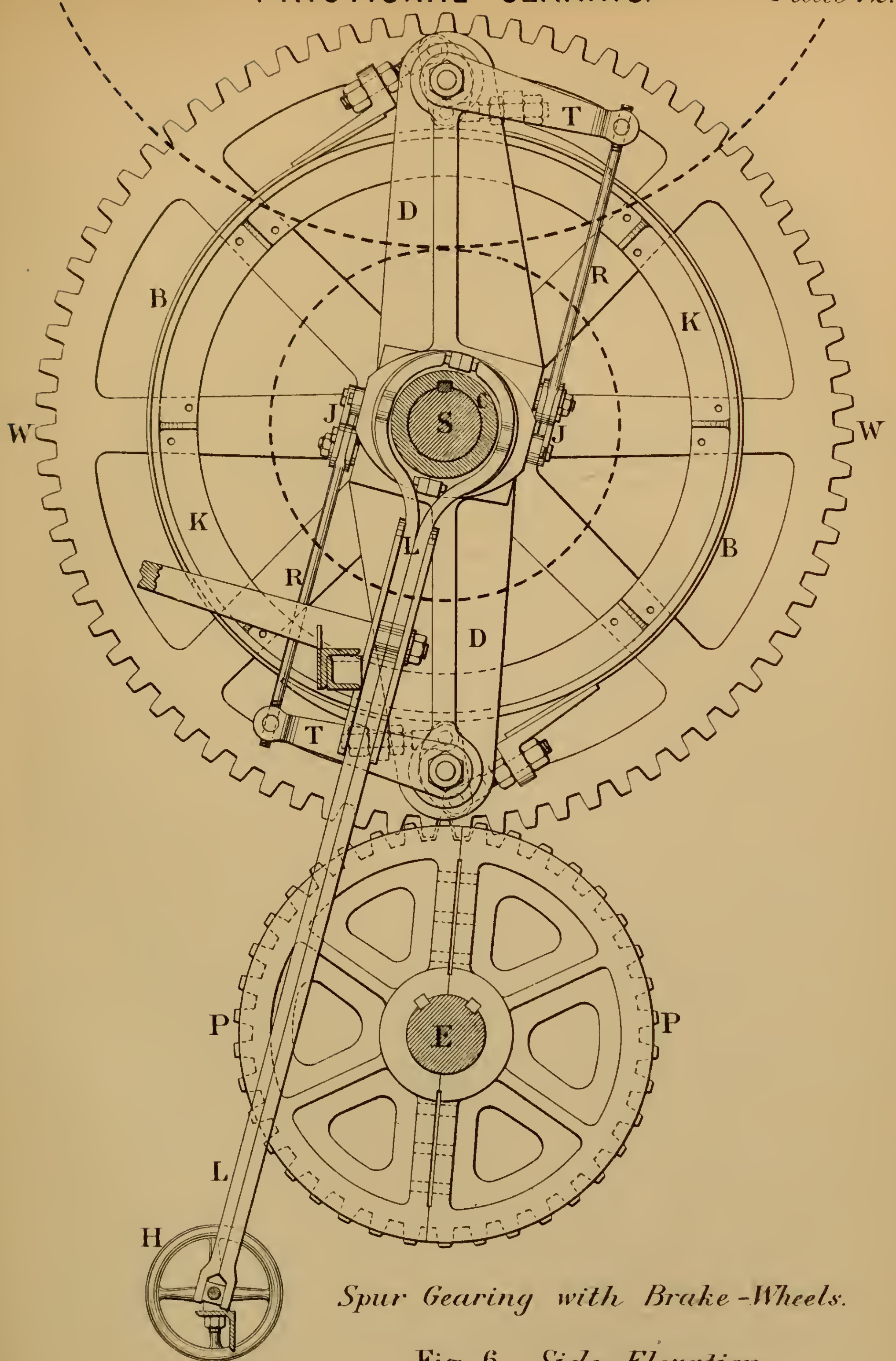


Fig. 5.

Brake band and T lever.

Scale 1/16th

(Proceedings Inst. M. E. 1888.)



Spur Gearing with Brake-Wheels.

Fig. 6. *Side Elevation.*

(Proceedings Inst. M. E. 1888.)

Scale 1/32nd.

Floor Line

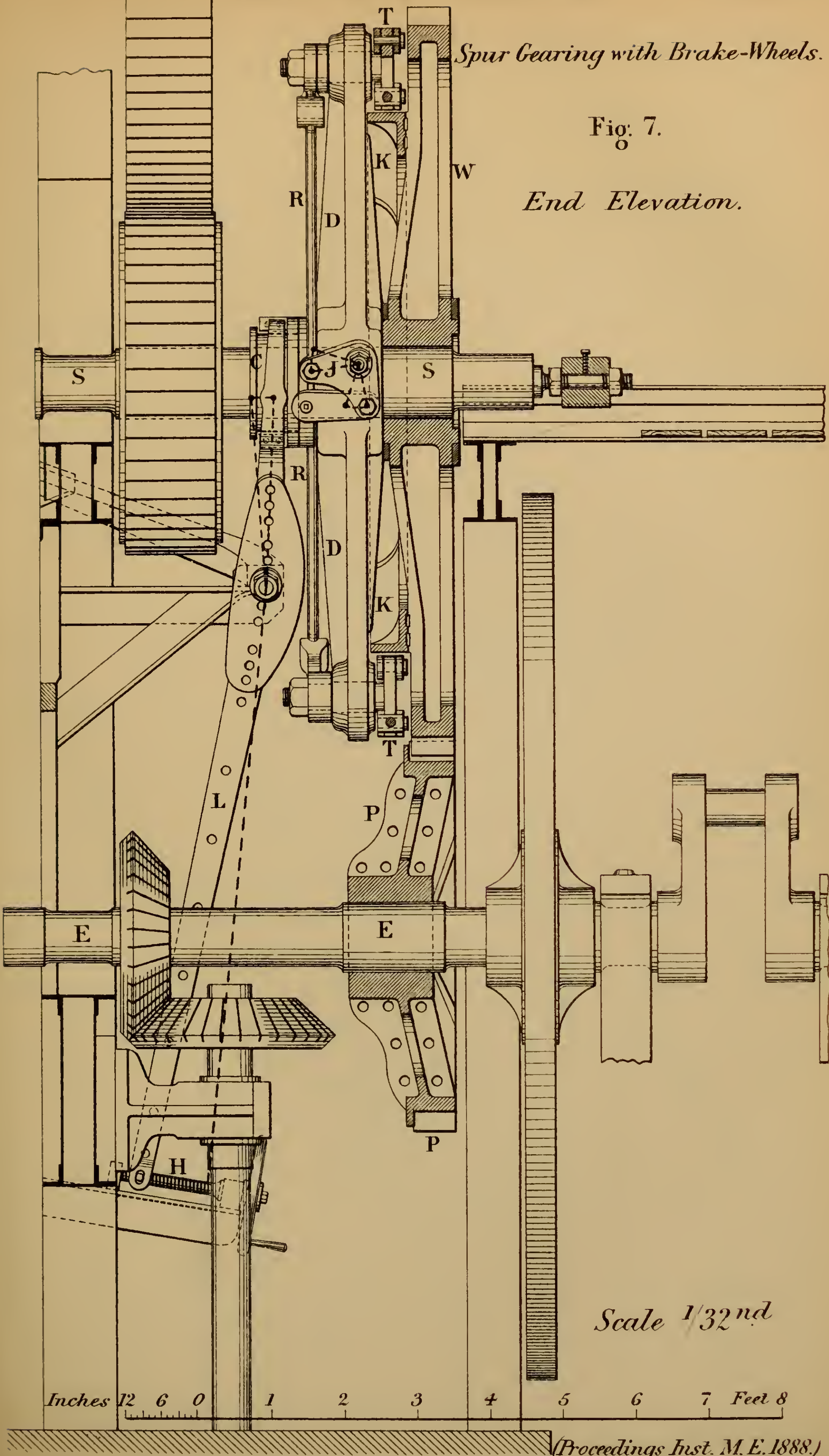
FRICTIONAL GEARING.

Plate 73.

Spur Gearing with Brake-Wheels.

Fig. 7.

End Elevation.



Scale 1/32nd

(Proceedings Inst. M.E. 1888.)

PORT OF DUBLIN.

Fig.1. *Plan of Dublin Bay and Port.*

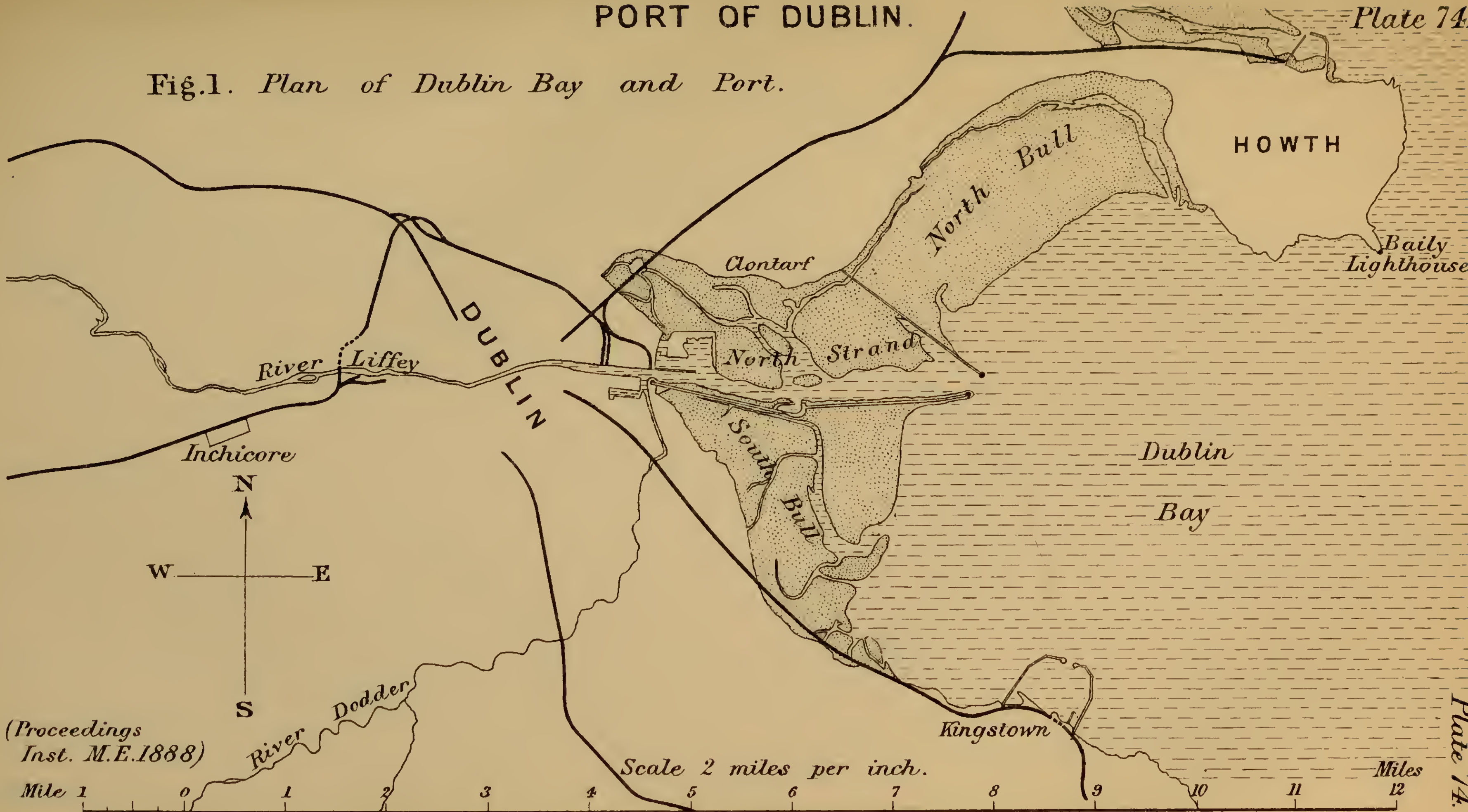


Plate 74.

PORT OF DUBLIN.

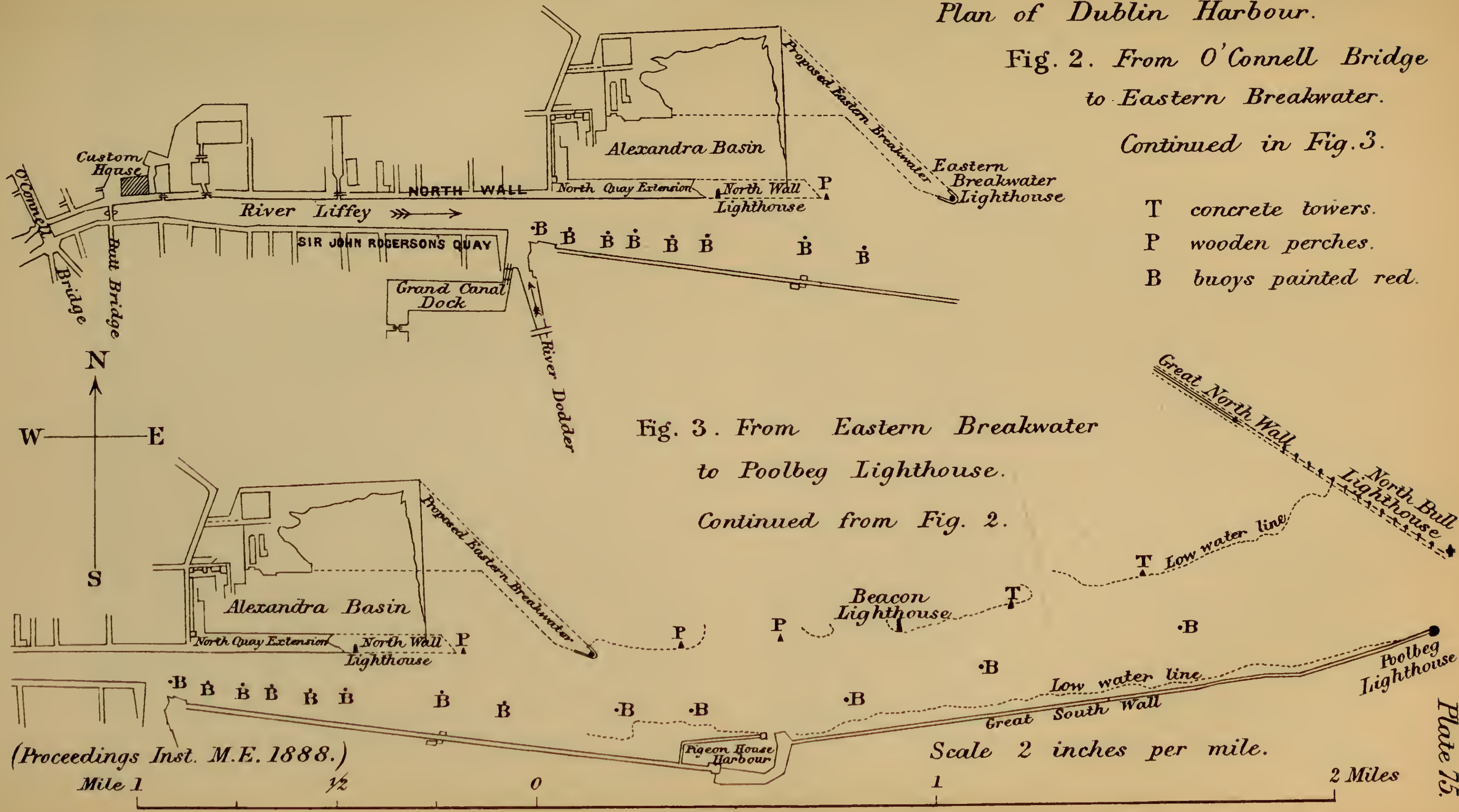
Plan of Dublin Harbour.

Fig. 2. *From O'Connell Bridge to Eastern Breakwater.*

Continued in Fig. 3.

Fig. 3. *From Eastern Breakwater to Poolbeg Lighthouse.*

Continued from Fig. 2.



(*Proceedings Inst. M.E. 1888.*)

Fig. 4. *Poolbeg Lighthouse.*

Fig. 5. *North Bull Lighthouse.*

(*Proceedings Inst. M. E.* 1888.)

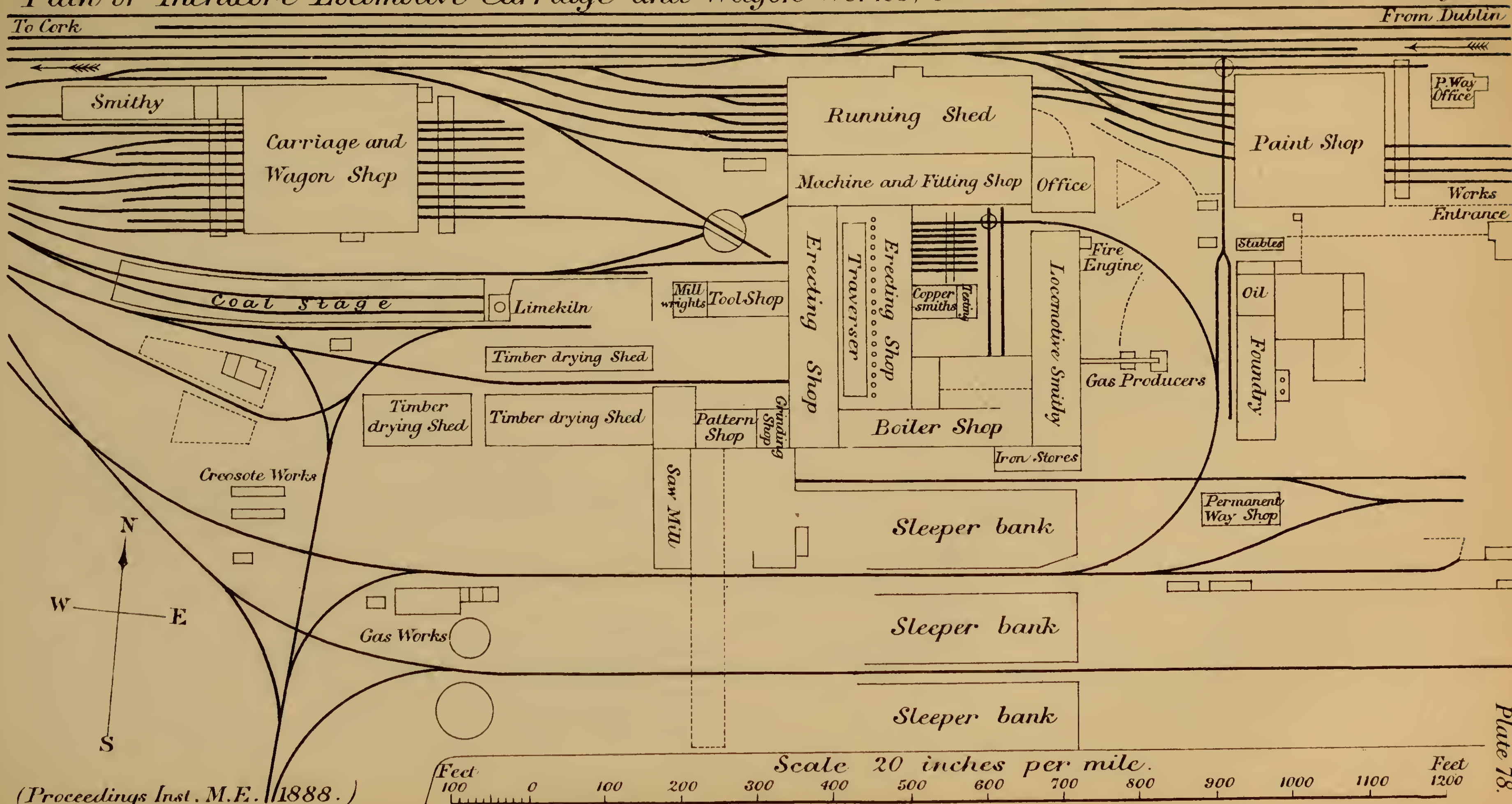
Fig. 6. *North Wall Lighthouse.*

Fig. 7. *View from South Quay, looking east.*

(*Proceedings Inst. M. E.* 1888.)

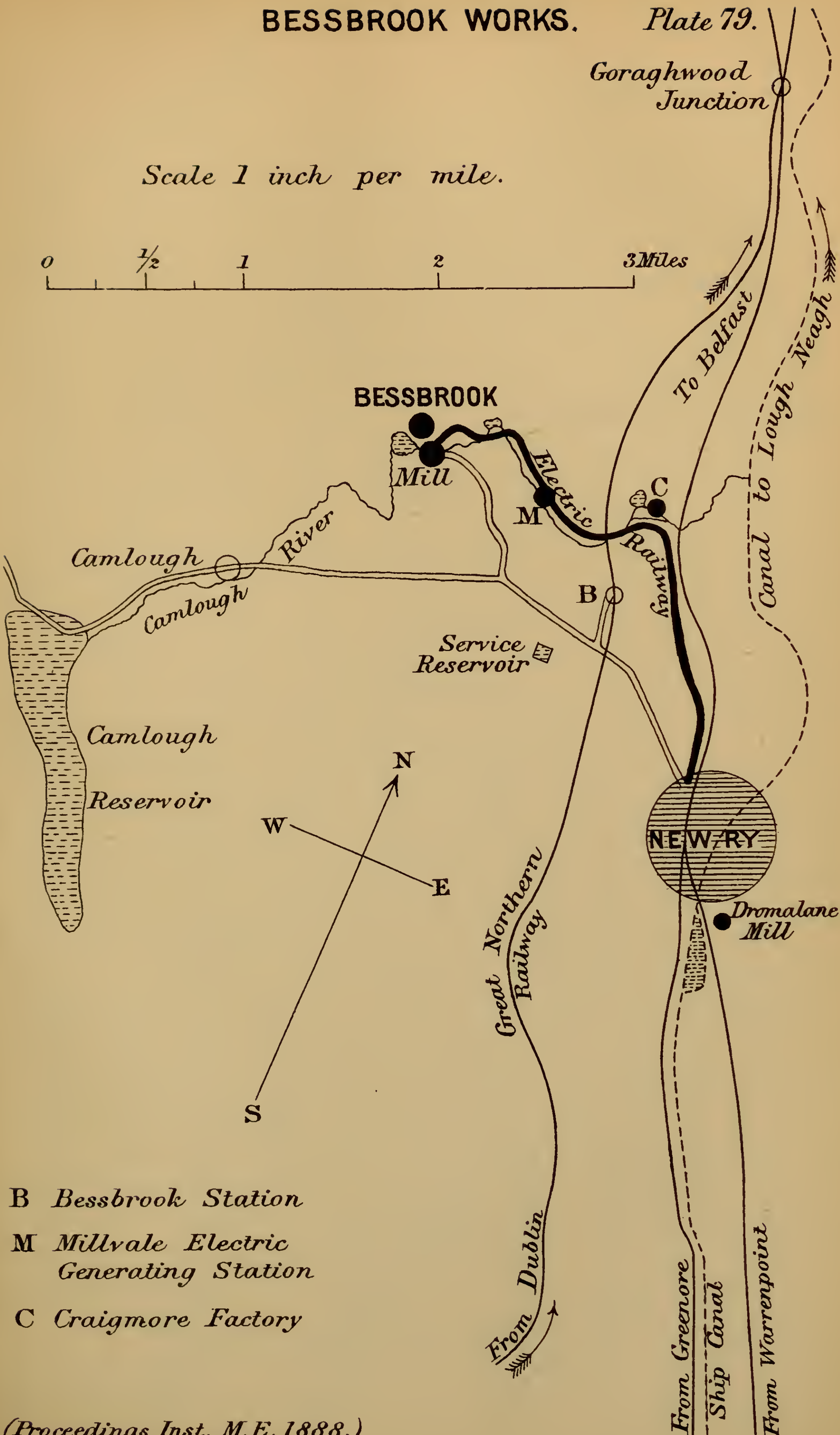
INCHICORE WORKS.

Plan of Inchicore Locomotive Carriage and Wagon Works, Great Southern and Western Railway.



(Proceedings Inst. M.E. 1888.)

BESSBROOK WORKS. *Plate 79.*

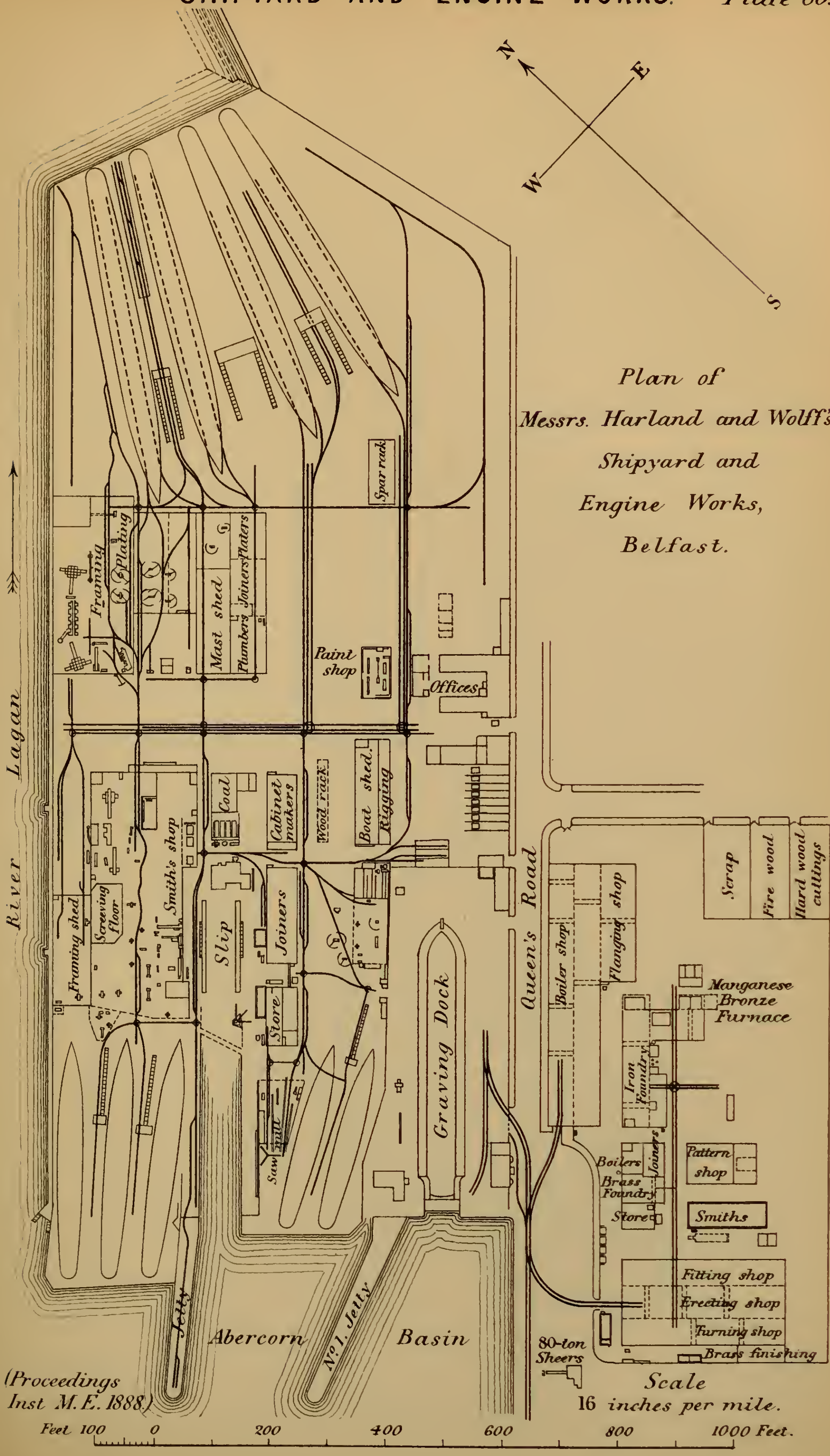


B *Bessbrook Station*

M *Millvale Electric Generating Station*

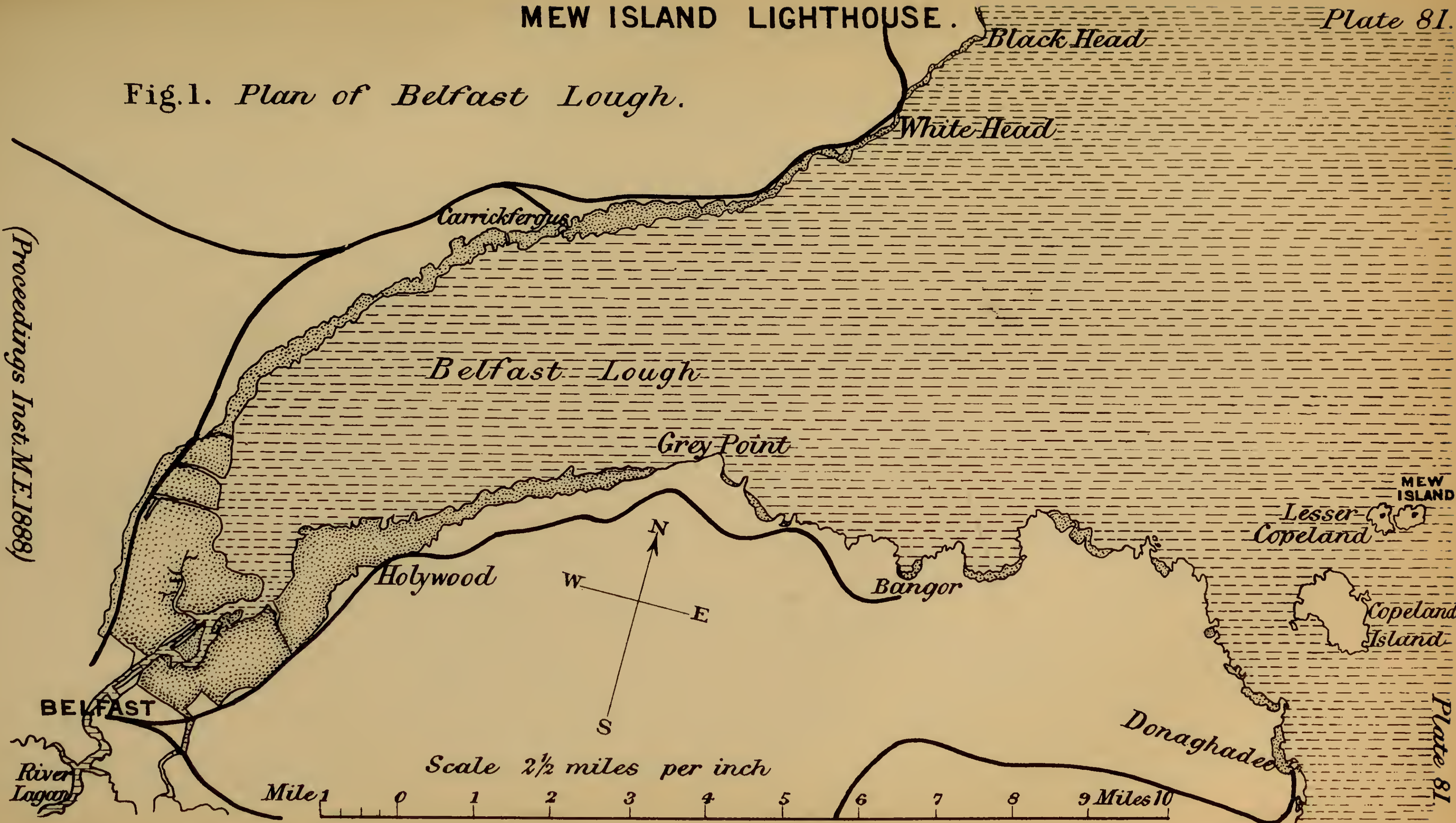
C *Craigmore Factory*

(Proceedings Inst. M.E. 1888.)



(Proceedings Inst. M.E. 1888.)

Fig. 1. *Plan of Belfast Lough.*



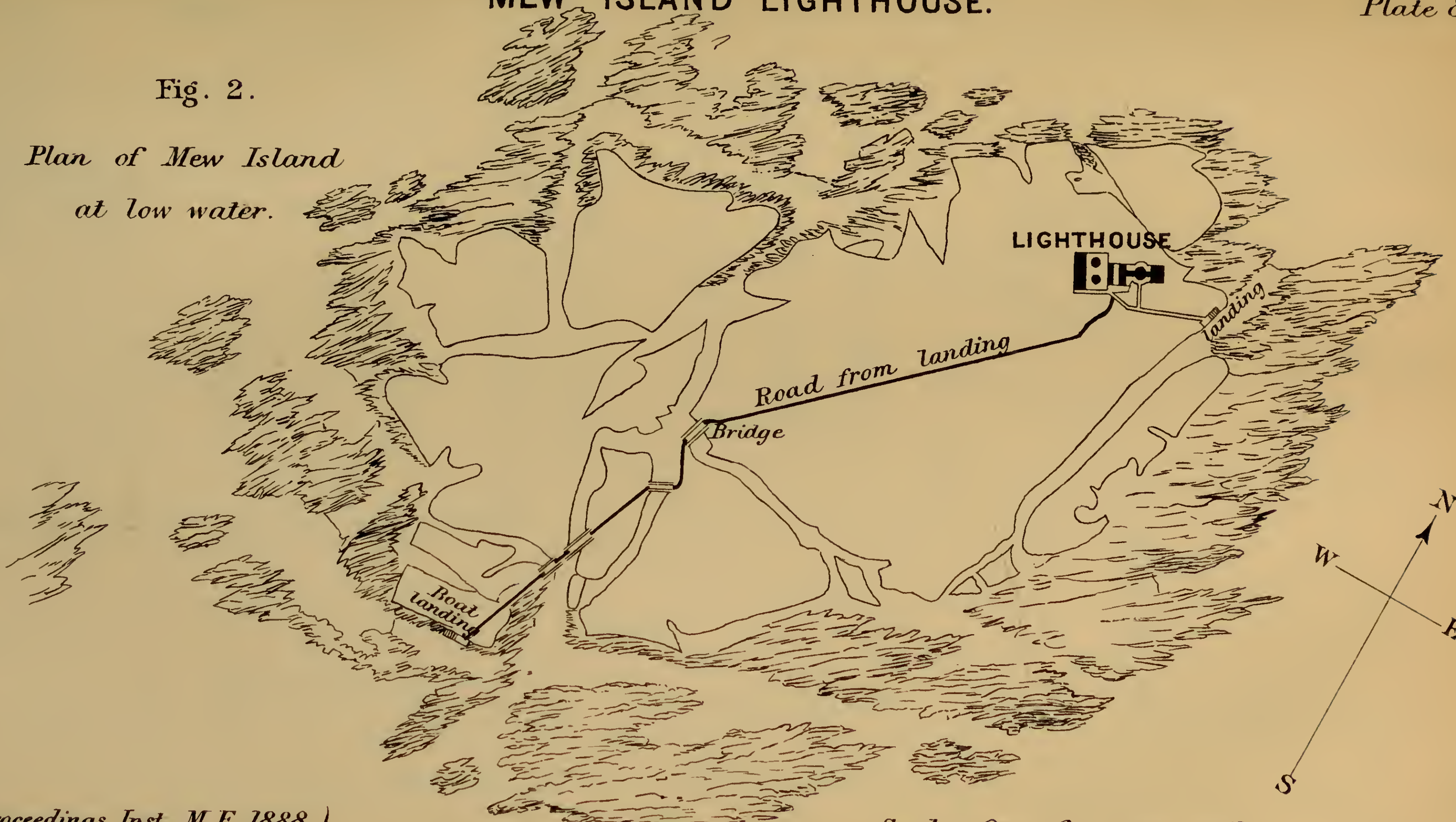
(Proceedings Inst. M.E. 1888)

Plate 81

MEW ISLAND LIGHTHOUSE.

Fig. 2.

Plan of Mew Island at low water.



Scale One foot per mile.

0 — 1/4 — 1/2 Mile

(Proceedings Inst. M.E. 1888.)

Plate 82.

MEW ISLAND LIGHTHOUSE.

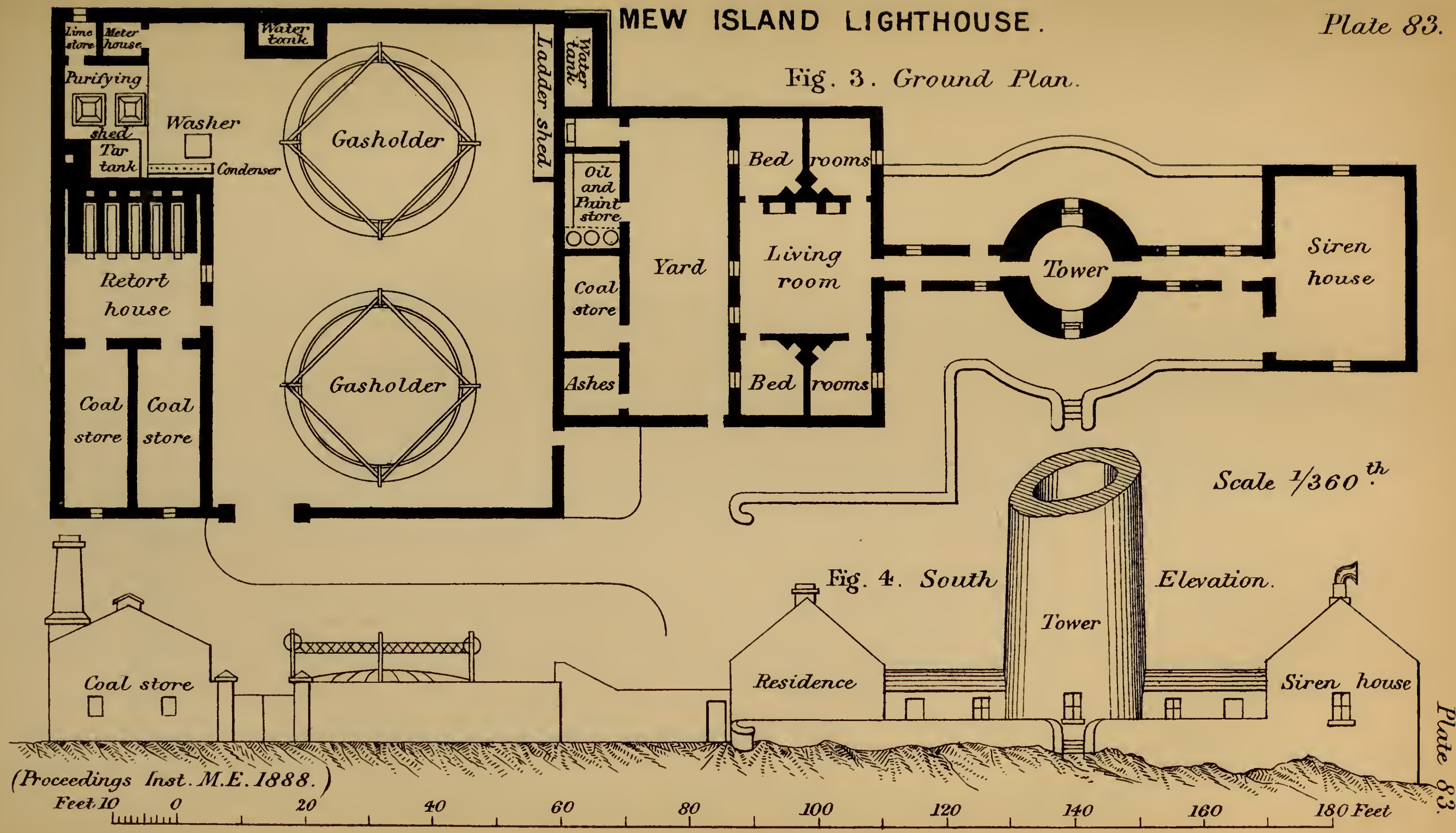


Fig. 3. Ground Plan.

Fig. 4. South Elevation.

Plate 83.

MEW ISLAND LIGHTHOUSE. *Plate 84.*

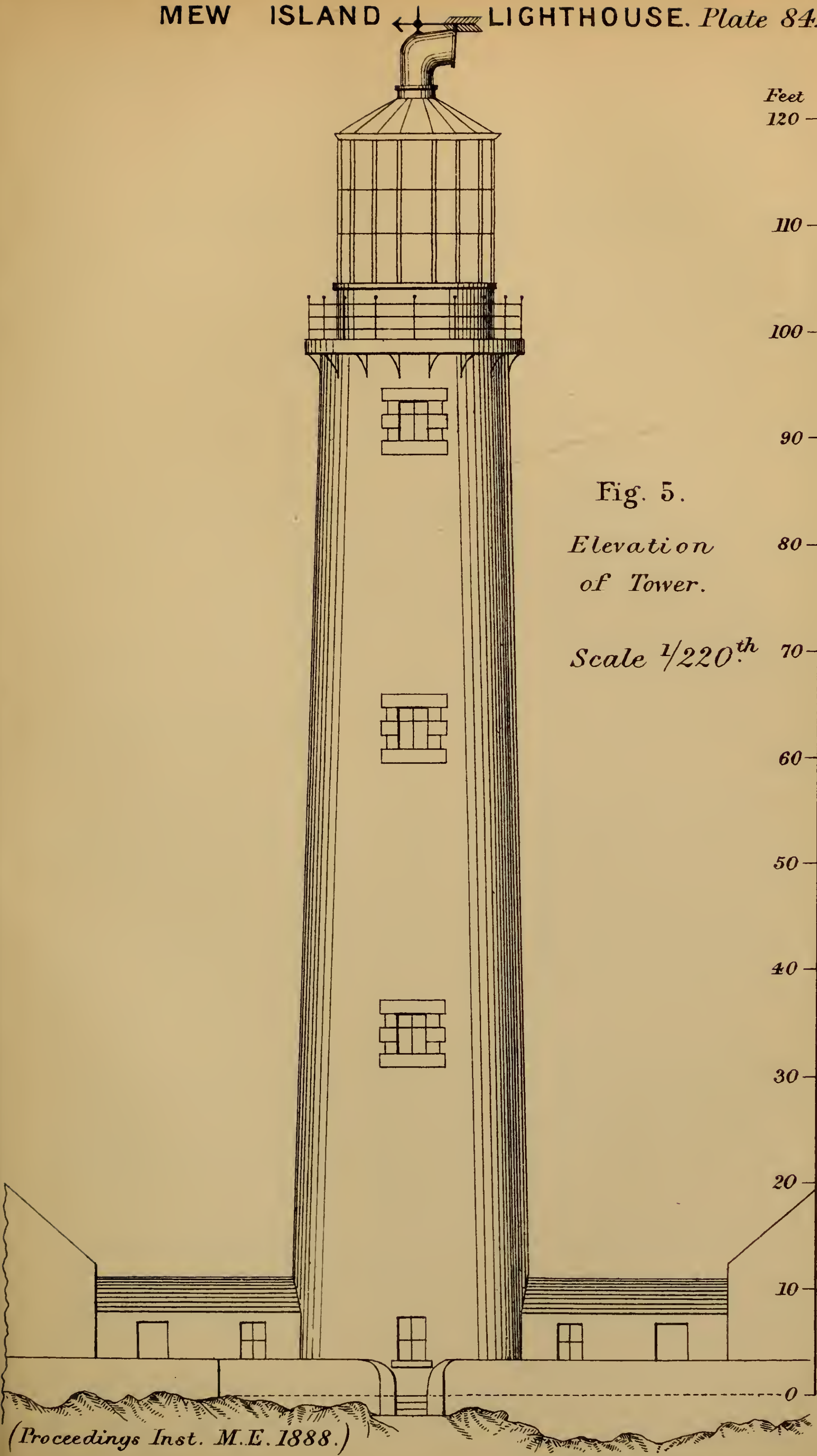


Fig. 5.

Elevation of Tower.

Scale 1/220th.

(*Proceedings Inst. M.E. 1888.*)

Institution of Mechanical Engineers.

PROCEEDINGS.

October 1888.

The Autumn Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Wednesday, the 24th of October 1888, at Half-past Seven o'clock p.m. In the absence of the President, Edward H. Carbutt, Esq., who was travelling in America, the chair was taken by Charles Cochrane, Esq., Vice-President.

The Minutes of the previous Meeting were read, approved, and signed by the Chairman.

The Chairman announced that, in connection with the recent Summer Meeting in Dublin, the Council had nominated as Honorary Life Members of the Institution the Right Honourable the Earl of Rosse, Chancellor of the University of Dublin and Chairman of the Local Committee for the Meeting, and the Rev. Dr. Haughton, Senior Fellow of Trinity College, Dublin, and Vice-Chairman of the Local Committee.

The Chairman announced that the Ballot Lists for the election of New Members, Associates, and Graduates, had been opened by a committee of the Council, and that the following twenty-nine candidates were found to be duly elected:—

MEMBERS.

William Borrows, ...	St. Helen's.
Augustus Hicks Henery Bratt, . .	Woolwich.
Frank Castle, ...	London.

2 o

Abram Combe, ...	Belfast.
James Edward Darbishire, . . .	Manchester.
Samuel Cleland Davidson, . . .	Belfast.
Charles Hastings Dent, . . .	Crewe.
George Eaton-Shore, ...	Crewe.
Gustave Joseph Fischer, . . .	Sydney.
Maurice Frederick FitzGerald, . .	Belfast.
Christopher Geddes, ...	Leeds.
Sir Edward James Harland, Bart., . .	Belfast.
Gustavus Charles Henning, . . .	New York.
Kyozo Kikuchi, ...	Osaka, Japan.
John Bruce King Macbeth, . . .	Bombay.
George Croydon Marks, . . .	Birmingham.
Charles Morris, ...	Calcutta.
Adolphus Nathan, ...	Milan.
William Eardley Norton, . . .	London.
William James Pirrie, . . .	Belfast.
Joseph Pogson, ...	Huddersfield.
John William Rock, ...	Sydney.
Walter Henry Wilson, . . .	Belfast.
Gustav William Wolff, . . .	Belfast.
Ethelbert George Woodford, . .	Transvaal.

ASSOCIATES.

Alfred Timothy O'Sullivan, . .	Swansea.
John Henry Rowell, ...	Gateshead.

GRADUATES.

Arthur Ashworth Bradley, . . .	Buxton.
Hubert Bindon Marten, . . .	Tavistock.

The Chairman announced that, in accordance with the Rules of the Institution, the President, two Vice-Presidents, and five Members of Council, would retire at the ensuing Annual General Meeting; and that the list of those retiring was as follows:—

PRESIDENT.

Edward H. Carbutt, ... London.

VICE-PRESIDENTS.

David Greig, ... Leeds.
Arthur Paget, ... Loughborough.

MEMBERS OF COUNCIL.

Benjamin A. Dobson, ... Bolton.
Edward B. Marten, ... Stourbridge.
Benjamin Walker, ... Leeds.
J. Hartley Wicksteed, . . . Leeds.
Thomas W. Worsdell, . . . Gateshead.

Of these the following offered themselves for re-election :—

VICE-PRESIDENT.

Arthur Paget, ... Loughborough.

MEMBERS OF COUNCIL.

Benjamin A. Dobson, ... Bolton.
Edward B. Marten, ... Stourbridge.
Benjamin Walker, ... Leeds.
J. Hartley Wicksteed, . . . Leeds.
Thomas W. Worsdell, . . . Gateshead.

The following nominations had also been made by the Council for the election at the Annual General Meeting :—

PRESIDENT.

Charles Cochrane, ... Stourbridge.

Election as Member.

VICE-PRESIDENTS.

1856. William Anderson, . . . London.
1879. Sir James N. Douglass, F.R.S., . London.

MEMBERS OF COUNCIL.

1859. R. Price-Williams, . . . London.
1873. John G. Mair, ... London.
1873. William Henry Maw, . . . London.

1874.	Dr. John Hopkinson, F.R.S., .	London.
1885.	Henry D. Marshall, . . .	Gainsborough.
1888.	William Henry White, F.R.S., .	London.

The Chairman reminded the Meeting that according to the Rules of the Institution any Member was now entitled to add to the list of candidates.

No other names were added.

The Chairman announced that the foregoing names would accordingly constitute the nomination list for the election of officers at the Annual General Meeting.

The Chairman gave notice, on behalf of the Council, of a motion to be proposed at the ensuing Annual General Meeting for the two following additions to the By-laws :—

New By-law, to follow immediately after the existing By-law 10 :—"The Council may at their discretion reduce or remit the "Annual Subscription, or the arrears of Annual Subscription, of "any Member who shall have been a subscribing Member of the "Institution for twenty-five years, and shall have become unable to "continue the Annual Subscription provided by these By-laws."

Addition to be made at the end of By-law 34 :—"and whose "subscriptions shall not have been remitted by the Council as "hereinbefore provided."

The Adjourned Discussion upon the following Paper read at the Spring Meeting was then resumed and completed :—

Description of Emery's Testing Machine; by Mr. Henry R. Towne, of Stamford, Connecticut, U.S.A.

Shortly before Ten o'clock the Meeting was adjourned to the following evening. The attendance was 92 Members and 51 Visitors.

The Adjourned Meeting was held at the Institution of Civil Engineers, London, on Thursday, the 25th of October 1888, at Half-past Seven o'clock p.m.; Charles Cochrane, Esq., Vice-President, in the chair.

The Adjourned Discussion upon the following Paper read at the Summer Meeting was resumed and completed :—

Description of the Compound Steam Turbine and Turbo-Electric Generator; by the Honourable Charles A. Parsons, of Gateshead.

The following Paper was then read and discussed :—

Description of the Rathmines and Rathgar Township Water Works; by Mr. Arthur W. N. Tyrrell, of London.

On the motion of the Chairman a vote of thanks was unanimously passed to the Institution of Civil Engineers for their kindness in granting the use of their rooms for the Meeting of this Institution.

The Meeting then terminated shortly before Ten o'clock. The attendance was 87 Members and 51 Visitors.

DESCRIPTION OF EMERY'S TESTING MACHINE.

By Mr. HENRY R. TOWNE, of Stamford, Connecticut, U.S.A.

(*See Proceedings May* 1888, *pages* 206–259.)

Adjourned Discussion, 24 *October* 1888.

Since the previous discussion in May, an Emery testing machine of 150,000 lbs. capacity, equal to 67 English tons or 75 American tons, had been erected in London; and Mr. Towne's invitation (page 225) had been issued to the Members to inspect it, and to send or bring with them any specimens which they would like to have tested by it.

Mr. Edward Reynolds had been pretty fully acquainted with Mr. Emery's testing machine from its commencement; and the conclusion he had arrived at on the whole was that the plan was unreliable, looking at the circumstances which might occur in actual testing, and not at the condition of the machine while it was being rated against a standard machine. It so happened that, when he made his own testing machine about sixteen years ago, the idea had occurred to him of using flexible bands or fulcrum-plates instead of knife-edges; but he abandoned it for this reason. In his machine for testing up to only 60 tons he had made the knife-edges of what he believed was the rather unusual length of 20 inches; and from his experience as a steel-maker, as to what a steel band should stand when subjected to repeated flexures however small, he came to the conclusion that it would not be desirable to make those flexible bands of steel of a higher tensile strength than about 60 tons per square inch. It followed that, even if there were a factor of safety of only four, there must be 4 square inches of section in the flexible fulcrum-bands used in tension, which with 20 inches width would require a thickness of 1-5th of an inch; and he did not see how to determine where the centre of flexure of that thickness would be. If

the band was of a steel like hard cast-iron, it would be perhaps at one-fifth of the thickness from one side; if it was of the very mildest steel, it would be a little nearer the compression side than the tension side of the band, instead of being in the centre of its thickness, as was commonly assumed. It was also necessary to assume, what was contrary to all his own experience, that a kind of steel could be found which had no friction whatever amongst its particles in bending, so that its bending was only storing up power to be given out again. Even supposing this great advantage to be gained, there was nevertheless introduced in the Emery machine a sort of dead friction which did not come out again, by the use of the glycerine in order to prevent the action from being too lively. That was the kind of false reasoning which seemed to him to run through the whole idea. In the Thomasset gauge, which steel-makers were obliged to use for testing steel made for foreigners, the great hydraulic pressure to be measured was received upon a small piston of about 1 inch diameter, to which was rigidly attached a larger piston of about 10 inches diameter, both being sealed by flexible diaphragms in the way supposed by the author to be new; and the pressure per square inch obtained on the larger piston was thus reduced to about one-hundredth of that on the smaller, and was indicated by a rising mercury column on the larger piston. Again the testing machine used at Woolwich was one made at Creusot for testing the specimen between two horizontal hydraulic cylinders, one a pulling cylinder and the other a hydraulic abutment, with a dial gauge upon each, by which it was imagined that it had been ascertained there was no friction; the result was actually read upon a Thomasset gauge. But whatever source of error there might be in either of these machines for the small tensions required was easily eliminated. In the Woolwich machine the pulling cylinder was fitted upon trunnions, so that it could be turned up vertically at right-angles to the horizontal position in which it worked; and by loading it with great lumps of cast-iron weighing as much as the maximum pressures used, the gauges were periodically checked and their indications corrected, whereby the accuracy was ensured of the indications obtained for the actual loads put upon it in

(Mr. Edward Reynolds.)

testing. That was all very well for such small pressures as were ordinarily used in that machine; but he still believed, possibly from long habit and experience, in knife-edges. After the reading of the present paper at the former meeting, he had lifted for the purpose of examination the knife-edge in his own machine, which was 20 inches wide for a load of 60 tons; and he had found that the mark made by the knife-edge on the flat face of the seat appeared more like a difference in the tarnish than anything else, but it could be felt a little with the finger nail. Even assuming that the conditions alluded to in the author's reply (page 247) had happened, and that in a machine with too short knife-edges, such as those in some of the old machines, the seat had become worn until the knife-edge was somewhat embedded in it; and supposing a bearing was thereby formed in which a friction of rocking might be imagined to exist: yet, if that friction of rocking was any greater than the elastic resistance to altering the shape of the knife-edge, the knife-edge would simply convert itself thereby at once into a plate-fulcrum like Emery's, by the compression and elastic alteration of the shape of the knife-edge, instead of by its sliding on the bottom seat. Beautifully and ingeniously though the Emery machine was worked out, another reason why he should not like to depend upon it at his own works was the absence of a sufficiently solid foundation, owing to the coal mines underground, in consequence of which a machine that was not properly self-contained, and to some extent independent of the most accurate levelling, would not do. The piston in the larger hydraulic chamber of the Emery machine appeared to be about 22 inches diameter, with only 0·015 inch clearance at bottom for its whole extent of motion; and it seemed to him therefore that a very small eccentricity in thrust or pull must cant it so as to make one edge bear on the bottom of the chamber, and so vitiate the indications; he did not see how even such a microscopic error as might arise from some of the specimens not being of equal strength on opposite sides could be thoroughly eliminated.

The Chairman asked whether Mr. Reynolds had discovered that the knife-edge in his machine, of which he had spoken as having

been made sixteen years ago, ever jumped in the way described in the author's reply (page 251).

Mr. Reynolds replied that his machine had been constantly used during the sixteen years, testing sometimes at the rate of thirty specimens an hour while they were doing government work.* When the specimen broke, there was a shock; but if there was a jump it was so minute that it could not even be felt by holding the finger on the plate or seat and against the knife-edge. There was a source of error in the machine, which in his opinion rather told against the idea of going to the extreme of an exceedingly high multiplication of leverage for lifting small weights, in preference to the opposite extreme of lifting a large weight with a small leverage. The water-pressure supplied all over his own works being not more than about 1 cwt. per square inch gave the great advantage for a testing machine of requiring a very large pulling cylinder, the friction of which was of no consequence because it only lifted the weight-levers by the pull which it exerted through the specimen, while the actual load was measured from the other end of the specimen by the levers. The cylinder in his machine was therefore made as large as 44 inches diameter, in order to get a sufficient tension with so small a pressure per square inch. The consequence was the great advantage that with $1\frac{1}{2}$ inch valves the water was turned on freely until a gauge showed a little pressure; then these valves were shut, and the further pressure was applied through a small valve only $\frac{1}{4}$ inch diameter; and with a needle point to this valve the load could be picked up quietly, thus minimising the risk of overstraining the specimen. But the shock of picking up the load with a leverage of 100 to 1, as required by the government specifications, made a really perceptible difference in the result. In the improved plan which they were now carrying out with the approval of the government inspector, a dial spring-balance, checked

* The reason why government tests can be made so quickly is because the exact elastic limit is not taken, but the permanent elongation is required not to exceed a fixed amount at a specified strain; after noting this, the strain is gradually raised to the breaking point.

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daily, was substituted for the dead weights at the end of the lever, and was used in conjunction with the needle-pointed valve, whereby the tension was gradually increased upon the specimen up to the maximum required, instead of suddenly picking up the load and thereby exceeding the supposed strain. It was worth bearing in mind that there was some appreciable difference in the results so obtained.

Mr. John Rigby, Superintendent of the Royal Small Arms Factory, Enfield, had seen the 150,000-lb. Emery testing machine exhibited in London, and had been much impressed with the beautiful workmanship displayed in its construction. But one point in regard to the proportions of the machine had struck him as being a little startling; a pair of screws only 4 inches diameter appeared to him to be hardly sufficient for the purpose of bearing the end pressure which would be thrown upon them in extending long specimens.

Mr. J. Hartley Wicksteed, Member of Council, said that a comparison in regard to inertia had been made by the author in his reply (pages 252–3.) He himself agreed with the remark made by Mr. Reynolds (page 451) that there was an appreciable resistance from the inertia of the weight, so that if the pull upon the specimen was made to pick up suddenly a weight upon the end of a lever or a series of levers, there was an appreciably greater pull upon the specimen than it was credited with, greater than that indicated by the position of the weight upon the lever. This he thought was a material point, and it had led at the former meeting to a good deal of discussion as to whether the inertia told more heavily against the specimen in the case of a large weight and low velocity, or in the case of a small weight and high velocity. The calculation made by the author in pages 252–3 went to show that the inertia told more against the specimen in the case of a large weight with low velocity. But there was a confusion in the figures given for confirming that view, which rendered the comparison not in any way a fair one. In measuring the velocity of the weight in the single-lever machine the author had taken the velocity at which the lever was moving; but

in measuring the velocity of the weight in the Emery machine he had not taken the velocity with which the weight was moving, but had taken only the extremely small distance through which the weight was able to move before it reached its stops, and had assumed that a whole second of time would be occupied in moving through that distance. But this assumption had nothing to do with the actual velocity at which the weight was moving. If it were preferred to substitute, instead of the resistance of inertia, the resistance of the stop, or the resistance of the viscous fluid, which was purposely made viscous with the glycerine, and which passed through pipes no larger than a straw, in either case the only result would be a still more unknown resistance against the specimen, and still less would the weight at the end of the lever system record the full stress upon the specimen. The comparison attempted was really no comparison at all, because the velocities were not compared: in the one case a distance had been taken which was not a free but a confined distance, and the arbitrary assumption had been made that this limited distance was travelled through in exactly one second, neither more nor less; while in the other case the distance was unconfined, and was that actually travelled through in one second.

Another comparison made by the author was not a fair one (page 250), where he reasoned upon a supposed rate of straining of one inch in 500 seconds, and said that, though possibly the whole of the balance-weights in the Emery machine might be thrown on in three seconds by just moving the handles, it was surely quite impossible in the single-lever machine to travel the poise-weight along to the end of its long lever in that time. That was so; but in the single-lever machine, which was generally made with a leverage of 50 to 1, the equivalent time available would be fifty seconds more, or fifty-three seconds to run out the poise-weight along the whole length of the lever; because, while the lever itself was travelling in indifferent equilibrium from the bottom of its 5 inches arc of vibration to the top, its back end was able to move through the 1-10th of an inch without in any way altering the balance, and without bringing the front end up against either the top or the bottom stop. During the whole time that the front end of the lever was travelling, the

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specimen could never be strained with any more weight than was due to the position of the poise upon the lever, plus the inertia of the poise. The inertia of the poise and the friction of the knife-edges were together so small that when the slender piece of silk which he now exhibited was put into the clip-boxes of the machine in the same position that the specimen would be put, and when the hydraulic cylinder was started to pull at it at the same rate at which it pulled at the specimen—which was much greater than Professor Barr's hypothetical rate (page 231) of only one-thousandth of an inch in a second — the thread of silk was able to raise the lever arm through the whole arc of its vibration; it contained therefore within itself sufficient strength to overcome all those unrecorded resistances.

The Chairman asked whether it was meant to be understood that the strength of the silk thread would balance the whole of the frictional resistances and inertia in the single-lever machine when fully loaded. Judging from the force required to break the thread, which he had himself just broken by hand, its strength appeared to him to be only about 3 or 4 lbs.

Mr. Wicksteed replied that the strength of the silk thread would balance and overcome all the frictions and inertias of the 100-ton single-lever machine when in equipoise but unloaded. As the weight was run out along the lever to balance a large load, the friction of the knife-edge would be increased, and so would the effect of inertia of the travelling weight, owing to its position on the lever being further from the centre of motion; but inasmuch as the dead weight of the lever and poise together amounted to 6 tons, the thread had to overcome a knife-edge resistance due to 6 tons when there was no load on the machine. Even therefore at the maximum testing capacity of the machine those resistances, supposing them to increase proportionately with the load, would not be multiplied more than seventeen-fold. He had not tested the strength of the silk thread, but thought it would be something more than 3 or 4 lbs. The author seemed not to be aware that lever machines

were constructed in which the levers had a free swing, which they could take without altering the stress upon the specimen.

With regard to the rating of the Emery machine, he could not understand how the elastic resistances were compensated for. It was admitted in the paper that, when the diaphragm plate was displaced out of its normal and neutral position into a depressed and constrained position, it offered elastic resistance. Besides the diaphragm plate which sealed the hydraulic chamber, there was also the annular diaphragm V, Fig. 11, Plate 36, on the upper face of the piston, for preventing any cross action such as had been alluded to by Mr. Reynolds (page 450); and these two plates kept the piston central in working, even though the load should not be applied with perfect symmetry. There were also some strong horizontal stay plates, for the purpose of preventing lateral motion and avoiding cross strains. All those elastic resistances were admitted in the paper; but there was another elastic resistance of which no notice had been taken. Supposing the fulcrum-plates to be in a state of ease, perfectly vertical and unstrained, they would offer no more resistance in one direction than in the other; and the least possible weight would move the levers either way. But when the machine was fully loaded, the bending of the levers themselves must neutralise some part of the motion transmitted from the short arm to the long arm, because when the weights were put upon the long arm of any lever they must have the effect of producing some flexure in it, and thus the alleged total multiplication of 20,000 times in the lever system (page 217) must be somewhat reduced. In this case the fulcrum-plates must be bent, and must every one of them be in a state of unequal strain on the two sides of its neutral axis. There were therefore these further elastic resistances to be allowed for, besides those of the diaphragms and stay plates; and they were all of them increasing resistances as the test proceeded from the lower to the higher loads. Now how were these elastic resistances to be allowed for? It was stated in the paper (page 211) that they were allowed for in a simple way: namely that, if they amounted altogether to one-thousandth part of the load, all that would have to be done would be to make the weights one-thousandth part lighter than if

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the mechanism offered no such resistance. But supposing that the weights when thus made one-thousandth part lighter were correct for compensating the elastic resistances when all the various plates and other parts were in a state of constraint, then on unloading the machine to begin a fresh test the plates would not be in a state of constraint, but in a state of ease and offering less elastic resistance: so that the same weights could no longer be right under the altered conditions. Yet the same weights had to be used for both purposes, because the weighing was done by four series of weights representing tens, hundreds, thousands, and tens of thousands of pounds. The tens were used not only to begin with while the machine was free, but they had to be used again after the machine was loaded, say up to 150 tons, if it were wanted to add 10 lbs. at a time to the load. To get some idea of the significance of this variation in elastic resistances, it must be borne in mind that the motion of the diaphragm in the larger hydraulic chamber was multiplied 600,000 times into the motion of the indicator bar. If that motion were not lost in the way that he had explained, the effect would be that when the diaphragm moved one-thousandth of an inch, which was the maximum amount accredited to it in the paper (page 210), the indicator bar would move 600 inches. But the indicator bar did not move at all; it was weighted down until that one-thousandth of an inch, instead of being translated into 600 inches, was not transmitted at all. This meant that it was all lost by the compression of the liquid, by the expansion of the chambers and pipes containing the liquid, and by the flexure of the levers; and hence arose those increasing resistances of constraint which he had mentioned. Now the inventor of the machine appeared to be perfectly aware of this difficulty, because he had taken every means to overcome it as far as skill and ingenuity could enable him to do so. He had got a thin film of liquid that was no thicker than three leaves of paper of the thickness of those used in the Institution Proceedings. He had developed such an amount of ingenuity that even after the description given in the paper it taxed the powers of an ordinary engineer to follow in his footsteps. For example, that film of liquid was so thin that no bubble of air could travel along it; he had therefore made circular

grooves or annular recesses in the faces of the two diaphragms forming the hydraulic chamber, for the purpose of letting the bubbles of air travel along those circular grooves, which also had a radial avenue to connect them together, whereby the bubbles of air could escape, so as not to make matters worse by having more air in the liquid than could be helped. Every means possible had been taken to reduce the quantity of the liquid; the pipes were made about the size of a wheaten straw. The lever system was made very heavy; and an amount of ingenuity had been exercised that was perfectly fascinating in its details. But even now, though he had himself taken considerable pains to understand the machine, he could not understand how the rating could be done so that the same weights should mean the same thing when the several parts of the machine were in constraint as they did when those different parts were in a state of ease. The result to his own mind was this: assuming the machine to be correct, it must be taken to be so from the maker's word; it could not be proved or reasoned out. Now he contended that, if an ordinary single-lever machine were taken of large proportions, so as to be as free as possible from flexure, and if it were tested up to a certain load, say 10 tons—a load that was practicable for the user to place upon the machine without undue expense—it might be safely inferred that it was correct also for multiples of that load; but if the machine described in the paper were tested up to a load of 10 tons, which would be a practicable load to apply without undue expense, it did not seem to him a safe inference that it would be correct also for increased loads, for the reasons which he had given.

Professor W. Cawthorne Unwin had never had any other than a purely scientific interest in the Emery machine, and he had long ago formed the opinion which he still held that it was by far the most accurate testing machine yet made. The very interesting discussion which had taken place he thought would satisfy the author, except in the single respect that some of the speakers, before they had seen the machine or taken sufficient trouble to understand its principle, had invented various reasons for regarding it as

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inaccurate. There was so great a likelihood of being wrong in inventing reasons for disbelieving a machine before seeing it, that it would have been far better to wait and witness its operation before urging objections against it. In speaking about the plate-fulcrums of the Emery machine Mr. Reynolds had said (page 448) that for his own machine a tensile plate-fulcrum would be required of 4 square inches section: whereas in the Emery machine the plate-fulcrum of 10 inches width and 0·06 inch thickness (page 216) being in compression had a section of only 0·6 square inch: so that whatever objection there might be to using a plate-fulcrum of 4 square inches section could not apply to the plate-fulcrums of the Emery machine. It had also been assumed by Mr. Reynolds that in using a plate-fulcrum it would be necessary to know where its centre of flexure or neutral axis was. But this was not required to be known in the least in the Emery machine, in which the fulcrum distances were not measured; the machine was rated by dead weights, wholly irrespective of any knowledge of the position of the fulcrums or length of the lever arms. That was the kind of speculative objection that had been made; and as far as he had seen, all the objections which had been made to the machine were exactly of that kind.

The whole discussion had turned a good deal on the question whether an accurate machine could be made with knife-edges, and whether the arrangement of fulcrum-plates in the Emery machine was better or worse than knife-edges. He did not himself go the whole length to which the author seemed to go in this matter, and he thought it possible that the author did not quite mean what he had said in his reply (page 247), in which his object had rather been to depreciate knife-edges; and perhaps what he had said was a little beyond the truth. For his own part he had not been able, any more than Mr. Reynolds (page 450), to detect the indentation of the plate on which the knife-edge rested. Even after the knife-edges had worked for a long time under pressures reaching occasionally four or five tons to the lineal inch, but commonly one or two tons, he had not found in them any perceptible deterioration; and perhaps therefore the author's reply had gone a little too far. The objection urged was no doubt quite right in principle, but it was a question of degree;

and he thought that, if the knife-edges were properly constructed, the degree of error introduced by their flexure and their indentation in the bearing plate was not so much in practical working as from theoretical considerations it might be supposed to be. It was possible he believed to construct a satisfactory knife-edge machine, but at the same time he did not believe that with a knife-edge such sensitiveness could be attained as was reached in the Emery machine.

A good deal of discussion had arisen about the question of inertia, and as to whether high multiplication or low multiplication was preferable. He had seen it argued mathematically that the effect of inertia in a testing machine increased as the square of the number of multiplications: so that in the Emery machine multiplying 600,000 times it must be something like 144 million times what it was in the Wicksteed machine multiplying 50 times; but anyone who had used the two machines would know that this was not the case. On this point the comparison made by the author was considered by Mr. Wicksteed (pages 452–3) to be not a fair one; but Mr. Wicksteed he thought had made a false comparison also. For he had assumed that the rate of motion of the indicator lever in the Emery machine was as much faster than in the single-lever as the multiplication of the one machine was greater than the multiplication of the other. Although it was of course a question of velocity, it was not right to assume that the velocities were in proportion to the multiplying powers of the two machines. The Emery machine was so much more sensitive than the single-lever machine, and the motion of the indicator lever so much more restricted, that it would never attain the velocity corresponding with its higher multiplying power. So far as he could see from theoretical considerations, the question of inertia was absolutely independent of the multiplying power: it did not matter whether the multiplication was low or high; while practically the quick indication given by the Emery machine of want of balance permitted a much earlier and more exact readjustment.

The so-called jump of the single-lever machine on the rupture of a specimen was a point which anyone practically engaged in testing would know something about. No doubt the author had taken his facts with regard to the large jump of the machine (page

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251) from some lever machine in which the spring of the machine itself was rather large. In his own single-lever machines he had never seen the lever jump. At the same time he had been rather surprised to find on careful measurement that the whole of the compression in the tall standard of the lever machine and in its foundations, during a test when there was a big load on, was a good deal more than he had previously supposed it to be. When there was the whole pull of 100 tons on the specimen, the support and foundations were compressed something like one-tenth of an inch; consequently at the moment the specimen broke, the support sprang up one-tenth of an inch, and whether it threw the lever off its bearings or not would depend on the weight of the lever itself resting upon the support. It was conceivable therefore that in the single-lever machine there might be such a jump as the author had spoken of. In any case the spring was rather objectionable, and should if possible be got rid of. The author was thus talking of something which did really occur in lever testing machines: a sudden release of the pressure did throw the lever up, and might even throw it off its support.

Mr. John Goodman said there was a single-lever machine at the Broadway Testing Works, Westminster, similar to Professor Unwin's, but about half the size, for testing up to 50 tons (page 229). When it was first put up, there had been some little trouble with the jockey-weight jumping out of the grooves in which it ran on the lever. The flanges of the wheels were about 1–8th of an inch deep; and when a specimen broke, the jockey-weight would frequently jump out of the grooves, showing that there must be a considerable amount of spring in the machine. He had mentioned that matter some time ago to Professor Unwin, who said that it had never occurred with his machine, and that he was always extremely careful to work with the steelyard close to the bottom stop. Having himself taken the hint, he had never had any further trouble in that respect; but in order to prevent the possibility of the jockey-weight jumping, he had put four little brackets underneath the guide of the jockey-weight, which of course had prevented any further

jumping. He had never known the lever to jump at the knife-edge, at least not appreciably.

With regard to sensitiveness, of course in the Emery machine, which had a multiplication of 600,000 times at the end of the indicator bar, the slightest amount of movement at the specimen would be immediately shown to the eye; whereas in the single-lever machine, which had a leverage of only 50 to 1, the same amount of movement at the specimen would not be rendered directly visible. In order to test the sensitiveness of the single-lever machine, he had on one or two occasions made use of a gravity-piece similar to that which Sir Joseph Whitworth had devised for his measuring machines, for measuring to one-millionth of an inch; between the bottom stop of the lever and the lever itself he inserted a small piece of metal, with a tiny weight attached tending to pull it out horizontally, so that the slightest motion of the lever would allow the piece to drop out. Then with a load of between 40 tons and 50 tons on the specimen, the mere act of pressing with one hand lightly on the top cross-head to which the specimen was attached would invariably cause the weight-piece to drop out, showing that there could not be a serious amount of friction on the knife-edges. The same point that had been tested by Mr. Wicksteed with the thread of silk (page 454) he had himself tested with weights in the 50-ton machine, and the addition of only 2½ lbs. on the cross-head would carry the lever right through its range from the bottom stop to the top; the addition could even be reduced to less than 1 lb. But too sensitive a machine was rather awkward to use. By lowering the adjusting weight on the vertical arm attached to the lever of the machine, the centre of gravity could be brought below the knife-edge, so that the lever should be in stable equilibrium; while by raising the adjusting weight it could be brought into perfect equilibrium, or even into unstable equilibrium, which latter condition was of course very undesirable. By carefully adjusting it therefore, the lever could be brought to almost any degree of sensitiveness.

In regard to the Watertown machine (page 207), he enquired why it was no longer used for testing up to its full load. When first

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erected it had been used to its full load of 800,000 lbs.; but in one or two papers read before the American Society of Civil Engineers it had since been stated that it was not now allowed to be worked much beyond one-half its full capacity. Had anything gone wrong with it, or was some accident apprehended in using it to its full power?

Professor Archibald Barr said that since the last meeting he had seen the Emery machine and examined it very carefully, and had certainly been confirmed in the impression he had previously received that the details were admirably worked out; and the workmanship was indeed what might be called perfect. But he must own that the objections which he had at first felt from a careful study of the drawings and description of the machine had not been removed by his inspection of the machine itself. Regarding the mechanical principles involved in the design of the machine, the difference between ascertaining the strength of a piece of material and weighing a mass of matter, on which his remarks (page 230) had been criticised in the author's reply (page 247), was that the inertia of the levers of a weighing machine could not affect the result of a weighing; whereas a specimen in a testing machine might be stressed much beyond the stress represented by the poise-weights, on account of the inertia of the levers and poise. If a specimen had to be tested to destruction, the determination of the maximum stress could not be a statical observation, at least in the case of a hard specimen, and might be seriously affected by inertia; but it was claimed in the paper (page 219) that the position of the indicator bar at the moment of fracture correctly indicated the want of balance.

His impression that the frictional resistance of the liquid in the small tube was one of the elements which rendered the machine workable (page 231) had certainly been corroborated by the author's reply, in which he said that it was necessary to add glycerine to the alcohol in order to make the machine work properly (page 248), and that the proper proportions had been well determined by experience. Now apart from considerations of convenience, the proper liquid

would evidently be one with no viscosity at all, because then the pressure in the two hydraulic chambers connected by the tube would be equal, if the inertia of the liquid in the tube were neglected. But if there were no such resistances in the machine as were due to viscosity and other causes, then the point of the indicator bar would have to move at the speed he had already calculated (page 231) of 600 inches per second for a motion of one-thousandth of an inch per second in the specimen. In page 230 he had not criticised in the sense implied in the author's reply (page 248) the statements made in the paper as to the wide range of speed which the Emery machine admitted of. That was indeed a most valuable provision, but it was not at all confined to the Emery machine: other machines certainly had the same provision for variation of speed in testing. What he had endeavoured to point out was that, even in the case of testing at the exceedingly slow rate of one-thousandth of an inch per second, the indicator bar would attain the velocity of 600 inches per second if the poise-weights were allowed to remain constant for an instant, provided there were no resistances; and that it was the resistances which prevented it from doing so, and thereby rendered the machine workable. Both in the paper and in the author's reply the velocity ratio of 600,000 to 1 was assumed to be maintained in the machine. Therefore if a motion of 1 inch were taking place at the indicator bar, it should mean a motion of 1–600,000th of an inch at the specimen. It had already been remarked by Mr. Wicksteed (page 453) that the author had compared the effects of inertia due to a velocity of one-thousandth of an inch per second at the specimen in the single-lever machine with those due to a motion of the end of the indicator bar through its whole range in one second in the Emery machine; and it had already been pointed out that there was no connection whatever between the two assumptions. He would remark further that he had himself made no mention of any resulting damage from the quick motion of the indicator bar, either to the stops or to a fly getting in the way, as suggested by the author in page 249; all that he had referred to was the effect of the inertia upon the specimen itself. The point was simply that, if the weight on the levers were just in balance with the stress on

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the specimen, and the specimen were moved by the straining press, the lever system ought to follow at the rate which was represented by the leverage of the machine, if the fluid friction and inertia introduced no element of error.

It was unnecessary to do more, he thought, than express his own concurrence with what Mr. Wicksteed had said (page 453) in reply to the author's remark in page 250 about the poise-weight in the single-lever machine not being capable of being run out along the lever rapidly enough for putting the whole load on the specimen as quickly as in the Emery machine. What he had already said (page 462) about the viscosity of the liquid applied to the author's remark in page 251 concerning the motion of the liquid in the small tube; and it would be noticed that the author's calculation regarding the quantity of liquid which would be forced through the tube, if his own criticisms were just, assumed that the hypothetical rate of motion of one-thousandth of an inch per second at the specimen was maintained during one second, whereas the question involved solely the *rate* and not the duration of the motion.

With regard to damage resulting from the jump of the knife-edges in the testing machine (page 251), he thought it was simply necessary to fall back upon practical experience. In the 100-ton single-lever machine at the Yorkshire College, which had been in use for some time, he had tested several hundreds of specimens, and could give some particulars respecting the present condition of the knife-edges. The application of only 1 lb. or at most $1\frac{1}{4}$ lb. at the upper clip-box when the lever was in equilibrium was sufficient to move it through the whole of its range. As to delicacy, he was satisfied that when the machine was unloaded he could detect the change of balance due to a load of one ounce on the clip-box. When the machine was unloaded there was a weight of at least four tons resting upon the knife-edge; and one ounce out of four tons was 1–143,000th part. If the machine was loaded to its full load of 100 tons, there would be 104 tons upon the knife-edge; and he knew no reason to suppose that the resistance would increase faster than the load. If therefore the load was thus increased 21 times, he believed he was right in saying that 21 ounces would probably

produce about the same effect when the machine was fully loaded as the one ounce did when it was unloaded. As already hinted in Mr. Goodman's remarks (page 461), the delicacy of the Emery machine was simply a question of multiplying power. But it was necessary to distinguish clearly between delicacy of that kind and accuracy. A machine might show the very least addition to the load; but it did not thence follow at all that it was giving accurate results. In regard also to the delicacy with which tests could be made upon the single-lever machine, he had made with the 100-ton machine two tests of the tensile strength of a piece of cotton thread. In that case of course he had not used the moving ton weight, because evidently its motion could not be read to a sufficiently minute amount; he had therefore used the loose vernier as the travelling weight. The results were that one of the pieces of cotton thread was indicated as breaking at 3·1 lbs., and the other at 3·5 lbs. On afterwards testing the same thread with a spring balance, its strength varied from 3 lbs. to $3\frac{3}{4}$ lbs. Therefore he could safely say that he had not been able to detect by this 3 lbs. test any error due to the friction of the knife-edge, although during this test there was a load of 4 tons upon the knife-edge.

In the comparison made by the author in page 253, which had already been referred to by Mr. Wicksteed (page 452), the definite quantitative conclusion was arrived at that the work done on the specimen, in virtue of the inertia of the levers and poise, was nearly five times as great in the Wicksteed machine as in the Emery machine. The comparison however was between the Wicksteed machine working with one speed of the straining press, and the Emery machine working at 1–750th part of that speed. He could not conceive how that could be thought to be a fair comparison to make between the two machines. The motion spoken of by the author (page 253), of only 0·02 inch per second at the weights in the Emery machine, corresponded with only $0\cdot02 \div 15{,}000 =$ 1–750,000th of an inch per second at the specimen, or only 1–750th part of the speed of 0·001 inch per second at the specimen in the Wicksteed machine with which the comparison was made.

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With regard to the author's further reply on page 253 to his own remark (page 233) about the lever remaining in balance when the highest load of the test was reached at the climax C in the autographic diagram, Fig. 32, Plate 42, it was evident that on arriving at this point, when the load was just about to begin to go down, a little more extension of the specimen would not affect the load either way; and therefore he thought he was right in saying (page 233) that, no matter what the inertia of the machine was, it would not seriously affect the determination of the maximum load upon ductile materials. The great point to remember was that in the Emery machine the weights required to be altered in order to balance the stress put on the specimen by the straining press: whereas in the Wicksteed machine, or any other simple machine of that kind, it was the position of the weight that actually determined the amount of stress upon the specimen.

In page 254 the author spoke of making a test in a dead-weight machine, and adding 5,000 lbs. at a time to the load upon the specimen. That was not an illustration adverse to the single-lever machine with its rolling weight moving gradually and slowly along the lever; it was much more adverse to the Emery machine, because in the latter there was a series of definite weights, each separately applied; and if, as the author supposed, a specimen which was expected to stand 80,000 lbs. gave way at 60,000 lbs., it might quite well happen in the Emery machine that the operator had gone on adding large weights too long, and so had got beyond the actual strength of the specimen: whereas in the Wicksteed machine, or any other machine with a moving weight increasing the load continuously, it was impossible to exceed to any such extent the amount of load which ought to be put on the specimen.

Mr. Gustavus C. Henning, representing Mr. Towne and having charge of the 150,000 lbs. Emery testing machine which the Members had been invited to inspect in London, showed a variety of specimens which had been tested in this machine, and also a number of separate parts of the machine itself. Among the latter were a pair of the diaphragms or sheets of brass, which had been soldered together to

make the brass bag or sack that held the liquid and formed the larger hydraulic chamber; also a reducer put together complete, as well as its component parts separately, consisting of the piston, the guide-ring guiding the piston, the hydraulic chamber containing the liquid, and the diaphragm, which as used in the reducer was simply a steel plate hardened and tempered and ground accurately to the exact thickness desired. It was of course an essential condition for the successful working of the machine that this diaphragm should never touch the bottom of the chamber at any point; if it ever did touch, the machine would not work. In all the later machines this single reducer was now replaced by a pair, arranged side by side in the scale-case, because it was found difficult to make one alone of these steel diaphragms work correctly enough; it was much easier to use two reducers, placing them directly over the plate-fulcrum, across its length. The bending of these plates was one of the resistances which necessitated the adjustment of the weights, not in exact proportion to the leverages, but in proportion to the leverages minus the elastic resistances which acted like a spring. He showed also some of the experimental diaphragms first tried, which had all been discarded in the course of time, because it had now been found out that the only ones which would answer in the reducer were these hardened and tempered and ground steel plates. A short piece was shown of the copper pipe which connected the larger hydraulic chamber with the reducer; the hole in it though small could be seen through. A smaller diaphragm of steel was the size used in pressure-gauges, in which the weighing mechanism was almost identical with that in the testing machine, except that the point of the indicator bar travelled round over a quadrant divided into the pressures to be indicated by the gauge. On this plan pressure-gauges had been constructed registering up to 10,000 lbs. per square inch with an accuracy of one-tenth of one per cent. for all the readings from nothing up to 10,000 lbs.; and Mr. Emery believed there was no limit to the magnitude of the pressures which could be measured, except the permeability of the material. The small steel diaphragm shown was identical with the diaphragms in the two pressure-gauges which

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the Whitworth Co. were now using at their works. The collection exhibited of the fillers or liners, which were used for holding the test-pieces in the machine, included those for squares, rounds, and flats. These holders he considered were really an essential feature of the Emery machine, which he had not met with in any other testing machine, and were well worthy of attention for holding specimens of merchant bars of all shapes as they came from the rolls. Among the specimens from compression tests were two cast-iron columns, each 1 inch diameter and 8 inches long, both of which had been bent half an inch out of line in the centre without breaking, although made of ordinary cast-iron, such as it was thought impossible to bend without breaking. This test therefore showed the accuracy with which the faces of the holders could be adjusted to the ends of a compression column in the Emery machine; for he did not know of any other machine in which such a result could be produced with ordinary cast-iron. The proof of how perfectly central the compression stress had been on these slim columns was that both of them before bending had upset in the centre to the extent of 0·06 inch increase of diameter, and also 0·03 inch at the ends. Any column ought to upset somewhere along its length before bending, if the material were uniform and if the machine applied the strain symmetrically. These two cast-iron columns were turned out of the shoulders of the missing parts of the tension test-pieces shown; and the position of the point of fracture of these tension test-pieces would be seen to be almost at the centre. That was another result which could not usually be attained, unless the holders pulled exactly symmetrically, and without the slightest disturbance of the test-piece; otherwise the cast-iron would break off in the shoulders, for it was well known that a piece of cast-iron could rarely be broken in tension except at the shoulders. These were the only two pieces of cast-iron which he had recently tested in tension, and he thought they afforded very good evidence of the accuracy of the mechanical work in the holders of the machine. The same thing was shown by the steel specimens exhibited, which under compression had thickened in the centre and at the ends, increasing in diameter at the centre from 1·125 inch up to 1·169

inch, where the elastic limit had been far surpassed; but between the centre and the ends the elastic limit had hardly been reached.

In regard to inherent friction in the fulcrum-plates of the Emery machine, he believed that, if the indicator bar went back to rest instantly after the full load had been removed, there could be no further resistance in the plates. That this was the case he should be happy to show to any of the Members who wished to inspect the machine now in London. If the full load of the machine were put on the test-piece and were instantly released, the indicator bar would come back, and without making more than two oscillations would come to zero and stay there. That seemed to him the best evidence that there was no resistance in the fulcrum-plates, and that there was no momentum in the machine beyond what was due to the sudden release of the total force applied.

As regarded perfection in knife-edges, he had met with no other machine so well constructed in that respect as the Wicksteed machine, although even of this machine he had not yet seen one example in which the knife-edges did not show the effect of wear; in the United States there were no such good machines at all, whether testing machines or scales or any other machines made with knife-edges. In the United States he believed there was no knife-edge machine of any kind which had been at work three months under ordinary wear without the knife-edges and bearings showing deterioration; the knife-edges were crushed, and the bearings showed an indentation. Recent examinations of knife-edges of English make had shown the same conditions. The knife-edge machines in this country which he had examined personally also showed the same thing. It was the design and manufacture of the knife-edges and their seats that determined their sensitiveness and accuracy; this at least was the conclusion he had come to as the result of his own observation. Although there were plenty of knife-edge machines in the United States, it was always found that, the moment a specimen broke, all the levers jumped, and every knife-edge jumped off its bearing, so that when it came down again it left its mark on the bearing. This was the case with every machine with which he had had experience

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there, whether made by Fairbanks, or Riehlé, or Ohlsen, or Gill, or any other maker. Moreover no railway company, especially in this country, bought any weighing machine without making a contract with the manufacturer to keep the knife-edges and the machine generally in order; and he believed it was mainly from the repairs that the manufacturers made a profit on their own machines. In the Wicksteed machine he admitted the knife-edges were larger and more rigid; recent examination of these however had shown that they were not much better than others.

With regard to the two screwed columns carrying the straining press, which Mr. Rigby thought were rather weak (page 452), several of the engineers who had been to see the machine had urged the same objection; and he had endeavoured to point out why they were not too weak. In making a compression test, when they were in tension, they were certainly strong enough for any strain that could be put upon them, because there was no tendency to go sideways. When the machine was used for tension tests, they were in compression; but by means of the tension holders the stress was always applied well within the bearings of the columns above and below, and consequently there was no tendency to deflect them sideways. In the government machine at Watertown, which was horizontal instead of vertical, those screwed columns were 8 inches diameter; being horizontal they rested on several bearings, which were provided with caps, on account of some of the government engineers fearing lest in a tension test the columns might possibly rise out of their bearings. The machine had since then been tried on tension specimens 28 feet long, and in no case had the columns been found to leave their bearings at all. The details of that machine were precisely the same as of the vertical machine described in the paper, and the columns had about the same proportion in regard to length and diameter; in the horizontal machine they did not rise and did not change their position with relation to the axis of the machine any more than in the vertical. The best evidence that nothing of the kind had happened was that both machines had been frequently used to their full capacity, and no weakness of the columns had ever been noticed. At several steel-works in America one of these machines was used every day for regular work.

In order to give an idea of the sensitiveness or accuracy of the Emery machine which had been used for rating or calibrating both the machine described in the paper and that now exhibiting in London, he had gathered the following particulars from some remarks made* by Mr. Emery himself on this very point. This calibrating machine was constructed without any hydraulic chambers and diaphragms, and was merely a plate-fulcrum lever weighing machine, in which the total load applied to the weighing platform was transmitted to a main plate-fulcrum and thence to a system of levers. On a testing machine, having a platform about 16 inches square, and capable of carrying a load of 60,000 lbs., a measurable movement of the indicator was produced by 1-10th of a pound, or 1-600,000th part of the load which the machine was made to carry. Again three standard ton weights, of 2,000 lbs. or 14,000,000 grains each, were weighed in an open room, where the wind acting on the platform and indicator of the machine was producing a disturbance sometimes of perhaps as much as 50 grains; each ton was weighed four times, and the maximum difference between the lightest and heaviest weighings was only about 100 grains, or 1-140,000th part of the load. On the same machine when weighing 500 lbs. or 3,500,000 grains, an indication visible at five feet distance was produced by the addition of only 2 grains, or 1-1,750,000th part of the load. In a still finer machine, arranged for weighing the permanent standards from which were to be made the weights supplied to other testing machines, the balance was so adjusted that with 200 lbs. or 1,400,000 grains on the platform the indicator would show distinctly 1-10th of a grain or 1-14,000,000th of the load; and in weighing the 200 lbs. nine times over, the difference between the heaviest and lightest weighings was only 1-2,350,000th part of the load.

There was an erroneous idea that the liquid which was said to pass through the small tube from the larger hydraulic chamber to the reducing chamber caused friction. But one of the conditions

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* Transactions of the American Society of Mechanical Engineers, vol. vi, 1885, pages 646–8.

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under which any machine was to be used for weighing purposes was that its indicator should come to rest. If the indicator was not at rest, there were some disturbing influences, and the weights on one side or the other were not exactly balanced. It was not until the indicator came to rest that it could be known positively that the weight had been correctly determined. Everyone who had seen the Emery machine at work he believed would admit that the indicator came to rest with not more than two oscillations, and could generally be kept within one-tenth of an inch on either side of the zero mark. As soon as ever the indicator remained at rest, there could be no transmission of liquid through the small tube to the reducing chamber; consequently there could be no friction in the tube, which was not small enough to have the effect of capillary attraction upon the liquid. What happened under any change of load on the machine was practically an instantaneous communication of pressure by means of the liquid, but not any transmission of liquid through the tube. If anything were to happen to make more than an infinitesimal quantity of the liquid pass through the tube, the machine would simply not work. The motion of the indicator being limited by the stop at each end of its range, whenever the indicator had come up to either stop it stopped all transmission of liquid; consequently there was no liquid friction. At the instant of the indicator being brought back to zero by adjustment of the weights, there would be a minute transmission of liquid, but only for that instant; and the instant afterwards the liquid was again at rest, and friction was again avoided. Consequently when the machine was used in the regular way, so that the indicator was kept in its normal position at zero or nearly at zero, there could be no resistance in the liquid, nor any transmission of liquid through the tube. The object of making the liquid viscous was not at all in order to render the machine workable (page 462), but only to make the indicator somewhat less lively and therefore more easily kept at zero and not subject to very rapid oscillation. That a viscous liquid was not at all necessary was shown by the fact that the most sensitive Emery machines were plate-fulcrum machines without any hydraulic connections whatever.

With regard to the effect produced on the test-piece by a minimum motion of the weighing levers, in a single-lever machine the extremity of the long arm of the lever was so far distant from the observer that a motion of 1-10th of an inch was barely visible, and might be taken as the minimum motion, because it could not be said whether the lever was floating or moving so long as it moved through a space of 1-10th of an inch only; within that space it might move up or down without the observer being able to say whether it was at rest or in motion. The test-piece being rigidly connected to the lever by the upper clip-box and to the pulling piston by the lower clip-box, there could be no motion of the lever without producing a corresponding effect on the test-piece. Hence with 1-10th of an inch of motion at the end of a lever multiplying 50 times, the test-piece might be shortened or lengthened 1-500th of an inch without the observer being able to see any such effect, since the lever would appear stationary to him. An elongation or compression of 1-500th of an inch in a test-piece of 8 inches length between its shoulders, which was the standard length of test-piece in Austria, France, Germany, and the United States, corresponded with a change of 1-4,000th of its length; and assuming the modulus of elasticity to be 30,000,000 lbs., this corresponded with a difference in load of 7,500 lbs. On the other hand in the Emery machine, although a motion of 1-100th of an inch at the point of the indicator bar was as clearly defined as that of 1-10th of an inch at the end of the single lever, yet taking again the minimum motion of the indicator as 1-10th of an inch, this corresponded with a motion at the test-piece of 1-3,000,000th of an inch, the multiplication being 300,000 times. Then an 8-inch test-piece stretched or shortened 1-24,000,000th of its length would be subject to a variation of load of $1\frac{1}{4}$ lbs., supposing the modulus of elasticity to be 30,000,000 lbs. as before. This showed that, if all parts of both machines were entirely rigid, the single-lever machine would be enormously sluggish, while the Emery machine would still have a visible motion for even slight changes of load. As materials however, so far from being rigid, were on the contrary quite elastic, the Emery machine had absolute freedom of motion of the indicator without possibility

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of producing any effect upon the test-piece; while the single-lever machine if equally elastic would always have considerable effect upon the test-piece, when the lever was allowed to vibrate even only 1-10th of an inch.

In reference to the adjustment of the weights in the Emery machine, and to Mr. Wicksteed's remark (page 456) that if the weights were correct when the machine was lightly loaded they could not be correct when it was fully loaded, it should be understood that in the rating of the machine the successive weights were severally adjusted so as to allow for the increasing resistance according to the higher stage at which they were called into play in the scale of loading. All the parts of the mechanism which offered varying resistances under increasing loads had been enumerated (page 455) by Mr. Wicksteed, who however had omitted to point out that these resistances were infinitesimal because the changes of form in all of those parts were all microscopic. Still in an apparatus of precision, even these minute variations must be compensated and not neglected; and they had therefore been mentioned in the paper in order to show with what precision the Emery machine had been rated. The objection based on the bending of the fulcrum-plates was quite groundless, as no such action of bending of the fulcrum-plates occurred without having also been compensated. The changes of form of the fulcrum-plates were not at all dependent, as supposed by Mr. Wicksteed (page 455), upon the load on the levers, because the latter were purposely made so rigid as not to be bent by the application of all the weights. It must be borne in mind that the lever on which were placed the whole of the weights, amounting altogether to less than 15 lbs. total, was a bar of steel 40 inches long and $2\frac{3}{4}$ inches deep and about 5-8ths inch thick, so that evidently no measurable deflection could be produced. Moreover when the indicator stood at zero, that is when the load was balanced, all the fulcrum-plates and levers were in their normal position, and could not be in the constrained condition supposed. On page 456 it was explained in a most curious manner by Mr. Wicksteed how the increased elastic resistances of constraint were produced; but the explanation was based on the supposition that the levers bent, which was entirely

erroneous. It was true that the liquid in the hydraulic chambers was compressed, and that these and the connecting tube expanded under the loads applied, thus allowing the weighing table to settle down through a microscopic amount. But this could have no possible effect upon the motion of the indicator, nor produce any loss of motion; it was a uniform effect due to the application of loads, and did not change the rate of multiplication in the least; for as soon as ever under a load of say 50 tons the machine had been brought into its balanced position, an increment of 10 lbs. would produce just the same effect as it did under any lower load, and the indicator would move just the same. A load of 50 tons could not be put upon a specimen until the weighing table had been depressed through a given amount; and the same for any other load. The depression of the weighing table did introduce the increased resistances of all the stay plates of every kind, and these resistances increased proportionately to the loads, and could therefore be readily compensated in adjusting the weights; but these increased resistances were only a few pounds, and should not be exaggerated into a matter of importance.

In regard to the further remark (page 457) that the accuracy of the machine could not be proved, but that the maker's word must be accepted for it, this was certainly not at all the case; nor was it at all true that a single-lever machine might be considered correct for all loads if it was correct up to 10 tons. All that was necessary to prove the accuracy of an Emery machine was to load it with weights up to its capacity by placing them directly upon the weighing table; there was in fact no other machine which was so convenient for calibration up to any desired load. In the single-lever machine however this could not be done without putting the user to undue expense; and therefore it was considered sufficient to test the machine up to 10 tons only. To go beyond a dead load of 10 tons in the single-lever machine would necessitate the construction of a suspended scale-pan capable of carrying a load equal to the full capacity of the machine, say 100 to 150 tons; and this would certainly be a very costly matter.

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In Professor Barr's remarks (page 463) about the velocity which he supposed the indicator must acquire, the assumption of a motion of one-thousandth of an inch at the lower end of the test-piece was a wrong one. The total possible motion of this part of the machine was very minute; it could never exceed perhaps 1-50,000th of an inch, which amount of motion could be produced only by loading the machine to its fullest capacity. As a motion of the table of 1-600,000th of an inch would bring the indicator to rest against the stop, it seemed unreasonable to assume the possibility of a motion of 1-1,000th of an inch, when all motion had actually ceased almost as soon as it had commenced. There was simply no possibility of acquiring a motion or velocity of 1-1,000th of an inch per second, and therefore the argument based on such an assumption was without reason. It should be borne in mind that in the Emery machine a definite deflection of the indicator corresponded with a given load; thus, whether a load of 1,000 lbs. or 150,000 lbs. were transmitted through the test-piece, an increment of 10 lbs. would in each case and always produce the same invariable deflection of the indicator of about 0·06 inch. On applying any increment of load after the indicator had been brought to its zero position by the adjustment of the proper weights, the resistances of the plate-fulcrums being called into play would instantly counteract any tendency of the indicator to move beyond a position of equilibrium; for should it pass beyond, then the resistance of the plate-fulcrums to flexure would bring it back, and it would come to rest. Thus if a load was uniformly increased, the indicator when left to itself, not being brought back to zero by adding weights, would immediately follow the load, indicating its magnitude at every instant, until the lever came against the stop. At this point all further action of the levers ceased, as they became a rigid body. If a load of 100 lbs. were thus added, it would just bring the lever against its stop; but the instant an equivalent poise-weight was applied, the indicator would return to zero. Thus at every instant the loads applied were exactly equilibrated by a known resistance. In the single-lever machine no such action was possible, and it was admitted (page 453)

that the force applied was not balanced until the weight was moved, even if the motion of the short end was 1-10th of an inch. Now while this motion was produced, unbalanced momentum was imparted to the lever and weight, together weighing 6 tons; and it was this momentum, and not really the force applied to the test-piece, which was equilibrated by the rolling weight. That was one of the radical differences between the Emery machine and all others: in the former all applied *forces* produced a given positive motion between certain fixed limits, which motion indicated definite quantities; in all others the *momentum* of moving parts due to velocity acquired was balanced; and for this very reason the single-lever machine with its ponderous weight and lever was apt to give wrong results.

In page 463 it appeared to be erroneously supposed that in the Emery machine the application of any weight on the lever system could produce an effect upon the specimen. This was one of the very essential differences between the Emery machine and others. Although every load applied to the specimen could be accurately and instantly determined in the Emery machine, yet no effect could be produced upon the specimen by adding the weights upon the lever system. Every change in position of the weight in the single-lever machine multiplying fifty times produced instantly a fifty-fold effect upon the test-piece, and therefore the overbalancing of the beam might produce a very serious error. But any overbalancing of the lever in the Emery machine could have only an infinitesimal effect upon the test-piece (page 473), and could never overstrain it at a critical point, as could happen in the single-lever machine.

With respect to the Watertown machine (page 461), there were statements in the papers read before the American Society of Civil Engineers which were misleading. The government considered there was no machine in the world which approached the correctness and sensitiveness of that machine; and they did not want by any means to risk an accident happening to it, as it could not be replaced in less than two or three years. Rather therefore than run the risk of having such a valuable machine injured, they preferred not to allow it to be used ordinarily for breaking specimens at a load

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higher than 400,000 lbs., although static loads of 800,000 lbs. were frequently applied; it was occasionally tried up to a higher load, in order to prove that its sensitiveness had not been impaired by use.

The Chairman was sure that every one who had seen the Emery machine and had read the description given of it in the paper would realise the difficulty of appreciating the fact that such heavy pressures could be measured with such a thin film of liquid as that of only 15-1,000ths of an inch in thickness in the larger hydraulic chamber. This had indeed appeared incredible to himself, until he reflected upon the experiments which had recently been conducted by this Institution with reference to the friction of metal journals upon their bearings. In those experiments it had been found out that there was a distinct liquid pressure existing in the oil, which tended to drive the oil out from the bearings, while at the same time the thin film of oil was keeping the two metallic surfaces out of actual contact with each other. This consideration had therefore assisted him in the appreciation of the fact that in the machine now described so thin a film of liquid could be employed for such purposes as were here indicated.

In connection with the Emery machine he had been struck with a little instrument which had not been noticed either in the paper or in the discussion: he referred to a delicate apparatus whereby sight and touch were supplemented by the aid of electricity in measuring the thickness of any piece brought for testing by the machine. It was so delicate that, where neither sight nor touch might be sufficient for determining a dimension with the required exactness, the ringing of a bell by electricity immediately revealed the point of contact of the measuring apparatus, and enabled the thickness of the piece to be measured with extreme accuracy.

The making of cast-iron that would bend (page 468) was by no means uncommon in this country. He had himself seen bars of cast-iron, three feet long between their supports and one inch square in section, refuse to break under a transverse load of between 900 lbs. and 1,000 lbs.; and they assumed a permanent deflection. Moreover

in Scotland it was the regular practice to cast certain articles in cast-iron, with the soft metal which was obtained there, and to bend them afterwards: casting them first perfectly flat, and then bending them into various curved shapes. Hence he did not wish Mr. Henning to carry away a wrong impression, and to think that engineers on this side of the Atlantic could not do what was done upon the other. Nevertheless he thought the Emery testing machine that Mr. Henning was now exhibiting in London—assuming its accuracy, which he did not see any reason to doubt—was certainly unsurpassed by anything that had been done on this side of the Atlantic.

The Members he was sure would all join with himself in passing a hearty vote of thanks to Mr. Towne for his paper, and also to Mr. Henning for his kindness in showing the working of the machine and representing the author in this discussion.

Mr. Towne wrote that he thought, after the remarks of Professor Unwin (pages 457–460) and Mr. Henning (pages 466–478), it was unnecessary to add any further reply from himself.

DESCRIPTION OF THE COMPOUND STEAM TURBINE AND TURBO-ELECTRIC GENERATOR.

By the Honourable CHARLES A. PARSONS, of Gateshead.

The Compound Steam Turbine has now been developed into a motor which utilizes steam with a high degree of economy. It possesses considerable simplicity, and its speed of revolution is high; and as dynamos working at a high speed combine cheapness and efficiency, the application of the steam turbine for driving them is at first sight a good one. The combination of the steam turbine and dynamo has involved a considerable departure from existing practice, and has necessitated much experimental work, and investigations on entirely new ground.

The first Turbo-Electric Generator, completed about four years ago, ran at 18,000 revolutions per minute, and gave six electrical horse-power; it has been in almost constant use since that time, and has done a large amount of work. The second, made shortly afterwards, runs at 10,000 revolutions per minute; it was placed on the Tyne Steam Shipping Co.'s steamer "Earl Percy," and has worked her 60 lamps ever since to their entire satisfaction; the cost of fuel and maintenance is very small, and the light remarkably steady. Generators were then made for supplying up to 250 lamps, and a large number of installations were carried out, which have given excellent results; the consumption of steam was about equal to that of a good high-pressure engine with single slide when working with the same steam pressure and driving a good dynamo; but so marked has been the economy realised in regard to lamp renewals, oil, attendance, and other items, that the generators have almost without exception given great satisfaction. It became essential however, if these generators were to be successfully adopted for large installations, that higher degrees of economy should be realised, more nearly approaching those of the best compound engines. Theory based on the authenticated performances of

water turbines and the laws of the flow of steam and gases showed that the turbo-electric generator possessed the elements of the highest economy, not merely comparable with the best known performances, but even superior to them. How far practice has come up to theory may be judged by the results given at the end of this paper, which it will be seen approach nearly the best results of ordinary engines working with the same steam pressures.

Compound Steam Turbine.—The compound steam turbine T, Figs. 1 and 2, Plates 85 and 86, consists of two series of parallel-flow or Jonval turbines, set one after the other on the same spindle S, so that each turbine takes steam from the one before and passes it on to the one following. In this way the steam entering all round the spindle from the central inlet I, Fig. 1, passes right and left through the whole of each series of turbines to the exhaust E at each end. The steam expands as it loses pressure at each turbine; and by successive steps the turbines are increased in size or area of passage-way, so as to accommodate the increase of volume, and to maintain a suitable distribution of pressure and velocity throughout the whole series of turbines. The areas of the successive turbines are so arranged that the velocity of the flow of steam shall bear throughout the series about the same ratio to the speed of the blades; and as far as possible this ratio of velocity is so fixed as to give each turbine of the series its maximum efficiency. The two equal series of turbines on each side of the central steam inlet I balance each other as regards any end pressure on the spindle of the motor, and thus remove any tendency to undue wear on the collars of the bearings B.

The turbines are constructed of alternate revolving and stationary rings of blades. The revolving blades *r*, Fig. 9, Plate 90, are cut with right or left-hand obliquity on the outside of a series of brass rings, which are threaded upon the horizontal steel driving spindle S, and secured upon it by feathers; the end rings form nuts, which are screwed upon the spindle and hold the rest of the rings upon it. The stationary or guide blades *g* are cut with opposite obliquity on the inside of another series of larger brass rings, which are cut in halves, and are held in the top and bottom halves of the

cylindrical casing by feathers. The set of blades on each revolving ring runs between a pair of sets of the stationary or guide blades. The passages between the blades in the alternating rings form a longitudinal series of zigzag channels when the machine is standing still, as seen at Z in Plates 86 and 90.

Bearings.—In Fig. 6, Plate 87, is shown full size a longitudinal section of one of the bearings. As it is impossible to secure absolute accuracy of balance, the bearings are of special construction so as to allow of a certain very small amount of lateral freedom. For this purpose the bearing is surrounded by two sets of steel washers 1-16th inch thick and of different diameters, the larger fitting close in the casing C and about 1-32nd inch clear of the bearing, and the smaller fitting close on the bearing and about 1-32nd inch clear of the casing C. These are arranged alternately, and are pressed together by the spiral spring N. Consequently any lateral movement of the bearing causes them to slide mutually against one another, and by their friction to check or damp any vibrations that may be set up in the spindle. The tendency of the spindle is then to rotate about its axis of mass, or principal axis as it is called; and the bearings are thereby relieved from excessive pressure, and the machine from undue vibration. The automatic oiling of the bearings by the screw J, Plate 86, almost entirely prevents friction and wear. The circulation is continuous, the oil being used over and over again; and as it deteriorates very slowly, and there is little waste, the consumption may be said to be unusually small. The oil is raised up to the screw J by the suction of the fan F acting upon its free surface in the stand-pipe P. By the screw J it is fed into the adjoining bearing, and is also forced along the pipe H to the two other bearings of the spindle. After passing through the bearings the oil flows back along the pipe K to the reservoir W, Plate 85, to be again drawn up thence through the pipe U by the fan and fed into the bearings by the screw. The throttle-valve V is worked by the movement of a leather diaphragm L, which the suction of the fan F tends to close against the tension of the spring A.

Turbo-Electric Generator.—In Plates 85 and 86 is represented a turbo generator of 25 horse-power actual. All the turbines are here of the same diameter, and the expansive action of the steam is utilized by varying the depth and pitch of the blades.

In Plates 88 to 90 is shown a 50 horse-power turbo generator, which may be said to be of the triple-expansion type, from the fact that it is made with three different diameters of turbines for the purpose of dealing more advantageously with the increasing volume of steam as it expands. The three barrels H K M of different diameters, Plate 89, contain the three successive sizes of turbines. In each barrel the blades are continuously varied in pitch, so that an almost perfect distribution of steam is attained; and each barrel by itself may be compared in some respects with a cylinder in a triple compound engine. In the larger sizes the blades are accurately curved, as shown at Z, Plate 90, as in the best water turbines. To prevent end pressure, the spaces at the ends of the corresponding barrels are connected by equalizing passages Q, Plate 89.

Including fluid friction, the theoretical efficiency of each turbine in the set is about 89 per cent.; and the mean efficiency of the whole set is theoretically about 87 per cent. of the power which should be given out in the adiabatic expansion of the steam. At each turbine the flow of steam is continuous, and proceeds unchecked to the next. The steam expands slightly in passing each set of blades, but without shock and with gradually diminishing pressure, the whole energy of expansion being utilized to carry the steam through the subsequent turbines.

With the continuous lubrication and small pressure on the bearings, there is no material wear; and as the steam has no cutting action on the turbines, the initial clearances remain the same. Therefore the consumption of steam in the turbo motor does not increase under the conditions of every day running, and after long periods of work has been found to remain almost the same as on the trial run. The power absorbed in friction in the bearings has been estimated: when they are cold it is considerable, amounting to over one-third of a horse-power per bearing; but when the oil

becomes heated to its normal temperature, it falls to less than twenty per cent. of this amount.

Dynamo.—The motor is coupled to the dynamo D, Plates 85 and 88, by a coupling socket with squared hole J, Figs. 8 and 9, which fits accurately upon the squared ends of the two spindles; this admits of the armature being easily withdrawn. The magnets are entirely of cast-iron, and usually are made with simple shunt-winding only.

The armature, Fig. 5, Plate 87, is of the drum type. The body is built up of thin iron discs, only 1-100th of an inch thick and insulated from each other by tracing paper; it is turned up, and grooves are milled out to receive the conducting wires. For pressures of from 60 to 80 volts, there are usually thirty grooves. The course of the wire is as follows:—starting at *a* it is led spirally through a quarter of a turn *b* round the cylindrical portion *c*; then passing longitudinally along a groove in the core it is again led spirally through a quarter turn *d* round the other cylindrical portion *c*, then through the end washer, and then back similarly through a quarter spiral turn *e*, and along the diametrically opposite groove in the core, and lastly through a little more than a quarter spiral turn *f*, back to *g*, where it is coupled to the next convolution.

The commutator is formed of rings of sections. Each section is formed of short lengths, and each length is dovetailed and interlocked between conical steel rings; the whole is insulated with asbestos, and when screwed up by the end nut forms with the steel bush a compact whole. There are fifteen sections in the commutator, and each coupling is connected to a section. The whole armature is bound entirely from end to end with pianoforte or brass wire.

Efficiency of Dynamo.—For a normal output of 400 ampères and 80 volts, the resistance of the armature from brush to brush is only 0·0025 ohm. The resistance of the field magnets is 23 ohms, or an electrical efficiency of just 98 per cent. There are losses due to eddy currents in the core and wire of the armature, and to magnetic retardation resulting from change of polarity of the core. These

losses have been ascertained by separately exciting the magnets from another dynamo, and observing the change of steam pressure required to maintain the speed constant; the corresponding power was then calculated. The commercial efficiency of this dynamo has been found to be about 95 per cent.

Electrical Control Governor.—On the magnet yoke is the electrical control governor G, Plates 85 and 88, shown one quarter full size in Figs. 3 and 4, Plate 87, the movement of which is caused by the attraction of the magnet yoke upon a small iron bar or needle *n*, finely balanced and pivoted on a vertical spindle; a spiral spring *s* resists this attraction. A double finger or arm *r* is keyed on the same vertical spindle; the end of each finger *r* is flat, and when opposite the inlet *i* to the air-pipe Y closes it. The spiral spring *s* is so adjusted by the movable head *h* that the greater the attraction the more is the inlet *i* closed by one of the fingers *r*. When the inlet *i* is open, the inrush of air along the pipe Y partially neutralizes the suction of the fan F, and allows the diaphragm L to extend, and so to open the throttle-valve V. The combination of the fan F, the diaphragm L, and the spring A, forms a good centrifugal governor; but alone it is not accurate enough in its action for electrical purposes, and requires supplementing by the delicate control of the finely balanced and pivoted magnetic needle *n*. So accurate is the governor with this addition, that, when the load is gradually varied from nothing up to the maximum, the variation in volts at the terminal is less than one per cent.

Steam Consumption.—As the result of careful tests made when exhausting into the atmosphere and giving off 32,000 watts, the consumption of steam per electrical horse-power per hour has been found to be 42 lbs. with a steam pressure of 61 lbs. at the inlet; and 35·1 lbs. with a steam pressure of 92 lbs. at the inlet. Tests made at Portsmouth Dockyard, and at Messrs. Weyher and Richemond's in Paris, have agreed closely with the tests made on the same turbo generators before they left the works at Gateshead. These tests have therefore confirmed the accuracy of the figures above given.

Durability.—After three years' working of ten hours daily, the wear on the bearings has been found to be very small; in some cases almost inappreciable. The blades or vanes of the turbines show no cutting action from the steam. The commutators in the larger sizes have stood this amount of work well, and when carefully looked after have suffered very little wear.

Advantages.—The characteristic advantages of the turbo-electric generators may be summed up as follows:—steadiness of the electric current produced, arising from the high speed and the momentum stored in the moving parts; freedom from accident, on account of simplicity and direct action; small first cost, and small cost of maintenance of machine and lamps; small consumption of oil; little attention required; small size and weight for the power developed, which is about nine watts per lb. of weight in the whole machine, including both engine and dynamo. Consequently they are specially suitable for torpedo boats and fast cruisers, where weight and space are of the utmost importance.

The number of these generators already (August 1888) supplied for ship and land installations represents an aggregate of more than 2,000 electrical horse-power.

Discussion, 1 *August* 1888.

The Hon. Charles A. Parsons exhibited a couple of specimens of the engine of different sizes, one with the cover removed to show the construction and arrangement of the series of turbines.

The President said all would admit that this was a new departure in high-speed steam engines, and the Members were very much obliged to the author for having brought this paper before the Institution. Judging from the drawings and the engine exhibited,

it appeared to him that the author had successfully overcome a great many difficulties which had hitherto beset high-speed engines. Considering that his engine could run at 18,000 revolutions a minute, without developing a large amount of friction, and without great consumption of oil and steam, it was clear that he had pretty well solved a problem which a good many engineers had been trying to solve.

Mr. John Sturgeon was particularly interested in this motor, because he was just now on the look out for a motor suitable for driving dynamos by compressed air for the purpose of electric lighting, to work in connection with the compressed-air power supply which would soon be in full operation in Birmingham. The idea there entertained was that the proper way to arrive at the desideratum of private electric lighting was to convey the motive power to the users, and by means of some apparatus of this description to enable each user of the electric light to apply his own dynamo on his own premises, thus enabling him to avail himself of the latest improvements. One of the disadvantages of supplying electricity from a central station was that the town would be committed on a large scale to a particular electrical apparatus, and unable to avail itself of progressive improvements without incurring heavy expense in alterations. Another drawback was that an electric lighting company had only the night hours during which to earn their profits, while during the whole of the day they had still to keep up their staff of men and their apparatus and to pay interest on their outlay, all for the sake of a period of about a thousand hours in the whole year, during which their establishment could be turned to profitable account. He had been informed that in Leamington the experience had been unfortunate in an endeavour to supply the electric light by distribution of electricity from a central station. On the other hand when motive power was supplied by a general distribution, so that it could be applied to a number of different purposes, as was intended to be done by the Birmingham company with which he was connected, the power could be used during the day for some three thousand working hours in a year;

(Mr. John Sturgeon.)

while in addition electric lighting when carried out on that plan would employ a further thousand hours of night work. Thus the distribution of motive power would practically enable four years' work to be done in the time of one year's work done by direct electric lighting from a central station where the work would be confined to the night hours. In Paris compressed air had already been extensively applied to electric lighting. By reason of the greater facilities afforded by the municipal authorities in Paris, M. Popp, who had for some time previously been working a compressed-air system for driving clocks, had been enabled, since the present work had been begun in Birmingham, to lay on a greatly extended system of compressed air, by means of which dynamos were driven for electric lighting in many of the principal buildings in Paris. Compressed air, he believed, would be much superior to steam for driving the turbine described in the paper, owing to the fact of air being practically double the weight of steam at the same pressure, and therefore much more suitable for the high-speed turbine, which by that means could be worked without the slightest inconvenience even in a private house. He should particularly like to have an opportunity of testing the apparatus with compressed air in Birmingham.

Mr. Henry Davey regarded this as the first real and successful rotary steam engine. Previous attempts at rotary steam engines he considered had in all cases been reciprocating engines, with the reciprocating parts more or less concealed under an appearance of constituting a rotary engine. Hero's reaction engine of two thousand years ago, the first steam engine ever made, had been a pure rotary engine; and the engine now described followed on its lines in that respect. It appeared to him that there must be a considerable difficulty here as regarded leakage; and he should like to have the benefit of the author's experience in reducing leakage. It was also difficult to see how this high-speed engine was to be applied to various purposes requiring lower speeds, such as marine propulsion and driving machinery generally. One obvious way of getting out of the latter difficulty would be by making the engine

larger in diameter, in the form rather of a fly-wheel than of an engine shaft like that now exhibited. He enquired also whether it was contemplated to make this a condensing engine, and if so what increase in economy was expected to be got from it thereby; it would be difficult to apply an air-pump of the ordinary reciprocating form to such an engine, but possibly some form of centrifugal air-pump might be devised which could be put direct on the turbine shaft and so answer the purpose in a simple way.

The most valuable part of the paper he considered to be the practical results which had been obtained; these were exceedingly good, and rather startling from an engine so entirely new and so lately put to work. The commercial efficiency of the dynamo was given (page 485) as 95 per cent.; and assuming 80 per cent. efficiency for the motor alone, the total mechanical efficiency would then be represented by $35 \cdot 1 \times 0 \cdot 95 \times 0 \cdot 80 = 26\frac{1}{2}$ lbs. of steam per indicated HP. per hour. That was a good result for an ordinary engine; but the best engines, such as triple-expansion marine engines, had a consumption sometimes considerably below 16 lbs. of steam per HP. per hour. Even the $26\frac{1}{2}$ lbs. deduced from the author's lowest statement of 35·1 lbs. appeared a much better result than he should have anticipated from the steam turbine, taking into consideration the loss by leakage and the difficulties in manufacture in producing the exact form necessary for the blades and so on. The author appeared to have departed from his original design of having a continuous expansion from beginning to end: instead of this he had here reduced the expansion to three stages, more nearly approaching the action in triple-expansion reciprocating engines. This alteration he thought a very good step indeed, whereby probably a much higher result would be obtained than by a strictly continuous expansion.

The Very Rev. Dr. Molloy mentioned that the author had been good enough two months ago to send him this engine to show at a lecture that he had given at the Royal Dublin Society, at which it had worked most satisfactorily, producing an electric current for the supply of incandescent lamps. Both from the description now

(The Very Rev. Dr. Molloy.)
given of the engine and also from his practical experience of its working, he had no hesitation in saying that for the purpose of electric lighting it was in the highest degree satisfactory. It gave promise of turning out one of the most important inventions of the present day. Its special merit for the purpose of electric lighting consisted in its perfect steadiness of action; and so far as he could judge from the theory of the engine, the pressure upon every blade in the turbines during the time of its operation, after it had reached its normal velocity, must be perfectly constant. In this respect it differed from every other form of engine at present existing; for in all other forms of engine the expansive force of the steam was applied in a succession of impulses, and these impulses being imparted to the dynamo naturally tended to produce unsteadiness in the electric light. Every impulse in the engine was accompanied by a change in the strength of the current produced, and every change in the strength of the current was attended by a corresponding change in the intensity of the light: so that, when incandescent lamps were fed by a current direct from a dynamo driven by any existing form of steam engine, the impulses of the engine could actually be seen in the pulsations of the light. That was a serious obstacle to the use of such lamps for the purpose of reading. So far as he could judge, this engine was capable of driving a dynamo so steadily as to furnish a current which would be perfectly constant, and incandescent lamps fed by the current would not be subject to any pulsation whatever. He desired to express the highest admiration for the extreme beauty and simplicity of this invention; and he trusted it would fulfil the expectations to which it had given rise.

In reference to the suggestion (page 488) that compressed air could be employed more satisfactorily than steam for working such an engine as this, it seemed to him that there would be no advantage in the use of compressed air which did not attend the use of steam. On the contrary there would seem to be a needless waste of energy, as it would be necessary to use steam power first to compress the air, and then the compressed air would have to do exactly that which the steam was capable of doing by means of this engine most efficiently of itself.

With respect to the dynamo described in the paper, of which it was mentioned (page 485) that the commercial efficiency was 95 per cent., he asked whether by commercial efficiency was meant the ratio of the electrical horse-power produced in the external circuit to the mechanical horse-power expended in driving the dynamo: understanding by the electrical horse-power of the external circuit the total electrical horse-power of the current produced minus the portion wasted within the dynamo itself. If he was right in understanding the commercial efficiency in this sense, then it would seem from the paper that this dynamo had the highest efficiency of any dynamo yet produced. In the Edison-Hopkinson dynamo, which had been subjected to tests of the most delicate kind, the commercial efficiency obtained had varied from about 85 to 93 per cent. No dynamo that he had before heard of had attained a commercial efficiency of 95 per cent., which would be very high indeed.

The Hon. Charles A. Parsons said the use of compressed air in the turbine had not yet been tried practically; but theoretically Mr. Sturgeon was quite right (page 488) in expecting a rather better duty than could be obtained with steam. Compressed air being heavier, the speed of its outflow through the turbine would more nearly agree with the speed of the blades, and the resulting efficiency would consequently be rather higher. Perhaps one difficulty would be that the compressed air would probably require to be heated, otherwise ice would be formed in the passages between the blades, due to the expansion of the air; but if the air was heated to 180° or 200° Fahr. that would probably be prevented.

Leakage had certainly been a great difficulty to overcome (page 488), and it was necessary to run the blades as near as possible to the casing in order to reduce it to the utmost extent. By recent improvements in workmanship the leakage had now been reduced to a considerable degree; and no doubt it would still be much further reduced in the future. At present indeed leakage was the principal cause of loss.

The President asked what was the amount of clearance between the blades of the turbines and the casing of the engine.

Mr. Parsons replied that the clearance was only 0·015 inch in the larger machine exhibited; and this clearance represented a leakage of about 15 or 20 per cent. This engine was capable of working up to 50 HP. with 90 lbs. steam pressure. The smaller machine exhibited was about 4 HP., and would work about thirty 16-candle-power lamps.

There was no reason why the engine should not be used as a condensing engine (page 489). Thus far there had not really been any opening for a condensing engine on this plan, and he had not yet made one; but the resulting efficiency would probably be very high indeed. The blades would of course be larger for dealing with the lower pressures of steam, and the leakage would be less: so that it would probably make a very good engine with very high efficiency.

With reference to the steam consumption (page 489), it was quite right to infer that, with a dynamo giving an efficiency of 95 per cent. and an engine giving 80 per cent., the consumption of steam at 90 lbs. pressure would be $26\frac{1}{2}$ lbs. per mechanical horse-power per hour. But having calculated out the actual efficiency of this motor, he had found it amounted to only between 50 and 60 per cent., while the dynamo gave 95 per cent.; and the theoretical consumption of steam at 90 lbs. pressure in a perfect engine exhausting into the atmosphere was about 18 lbs. weight of steam per mechanical HP. per hour.

As to the commercial efficiency of the dynamo (page 491), the cause of its being so high was the high speed. As the magnetising current necessary to keep up the magnetism in these magnets was only about 1 per cent. of the total current produced by the machine, a larger loss could be afforded in other places. The loss in the conducting wire of the armature was very small, only 1 or 2 per cent. The energy required to magnetise and de-magnetise at so high a speed the iron core of the armature, although composed of very thin iron discs, yet constituted a considerable portion of the total loss.

In conclusion he wished to say that he was much indebted to Mr. Cross of Newcastle, Mr. William Anderson of Erith, and

Professor FitzGerald of Dublin, for the valuable assistance they had given him in the development of both the dynamo and the motor.

The President considered this paper was too valuable for the discussion upon it to be closed at present. He would therefore not ask the Members to pass a vote of thanks to the author now, but would adjourn the discussion in order that it might be resumed at the next meeting, at which no doubt further information would be elicited on this important subject.

Adjourned Discussion, 25 *October* 1888.

The Hon. Charles A. Parsons exhibited a turbo-electric generator of about 7 H.P., which would work about sixty 16-candle-power lamps. He showed also separately the spindle of a triple compound turbine of about 20 H.P.; and numerous specimens of the revolving and stationary rings of blades, for spindles and casings of various sizes; and specimens of the bearings, and the steel washers composing them; and an armature.

The Chairman said the turbo-electric generator supplied to his firm at the Ormesby Iron Works, Middlesbrough, had now been at work there for about twelve months, and they were extremely pleased with it. The first outlay, as stated in the paper, was comparatively small, amounting in this case to £716 17*s.* 11*d.* For that sum the machine had been applied to seven arc-lamps of 3,000 candle-power each; but now the same apparatus was found to be capable of doing far more work, and in a short time they expected to have it working with eleven lamps of the same power. The annual expenses also were moderate, amounting to £131 14*s.* 4*d.*, which included an annual overhaul, carbons costing £65, brushes £13, oil £6, other stores £13 5*s.*, and labour £23. It was necessary

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(Mr. Charles Cochrane.)

to go through the whole apparatus every twelve months to see whether it was in perfect order, which was done at a cost of £11 9*s.* 4*d.* These figures were based on the actual results of six months' working, and were exclusive of steam, and interest and depreciation; the cost of maintenance and repairs might possibly increase with age. There was some difficulty in ascertaining the quantity of steam consumed, because it was taken from the gas-fired boilers that supplied the blast-engines and hoists, &c.; but the representations made by Messrs. Clarke Chapman and Parsons with reference to their contract had been found to be so fully borne out that he believed complete reliance might be placed upon what they had stated to his own firm in regard to steam consumption:—namely that each lamp of 3,000 candle-power required $1\frac{1}{4}$ I.H.P., and that the generator consumed $3\frac{1}{2}$ lbs. of coal per I.H.P. per hour. The coal consumption per hour would thus be 31 lbs. for the seven lamps, and the corresponding steam consumption 337 lbs. per hour, taking the evaporative duty of the Roots boilers used at Ormesby as 11 lbs. of water per lb. of coal. The average time of burning each lamp throughout the year was 50 hours per week. Hence the total steam consumption per year was 391 tons; and the equivalent coal consumption per year would be $35\frac{1}{2}$ tons, costing £10 14*s.* 6*d.*, if coals instead of gas were used for raising steam. Adding $7\frac{1}{2}$ per cent. for depreciation and 5 per cent. for interest on the original outlay, and taking the foregoing estimate of the other annual expenses, with the addition of certain extras connected with the early working of the apparatus, the cost per lamp of 3,000 candle-power was found to work out to £38 12*s.* 1*d.* per year, or 3·57*d.* per hour.

Everything was beautifully balanced in the generator; as described in the paper, the longitudinal forces or end thrusts balanced each other perfectly, in consequence of the outflow of the steam towards each end alike from the central inlet. The author he believed had some special means of grinding the spindle for greater accuracy, not trusting to the ordinary strength of the spindle against the pressure of the tool upon it, but protecting it from deflection by grinding it in successive short lengths strongly

supported, and so getting more perfect work by instalments along the whole length of the spindle, thus producing the magnificent work seen in the spindle now exhibited.

Sir James N. Douglass, Member of Council, said he had watched this instrument from its early development, and had had several opportunities of closely inspecting it; and he was full of admiration for the beautiful contrivance which the author had succeeded in so far perfecting. There were several very important points connected with it: one was the high speed, and another the perfect steadiness of action. With regard to the latter, he might mention that when visiting the Glasgow exhibition he purposely went a second time in the evening in order to see some of the electric lighting machines at work, especially the one described in the paper. Although he had seen it several times before, he confessed that he was so perfectly deceived by its steadiness as to ask the attendant whether the machine was going to be run. There was the machine itself running before him, but so steadily that there was no visible sign of motion and no flash of the commutator; and it was only on examining it closely that he found it was actually running. That was enough he thought to satisfy any practical mechanic that the machine was almost absolutely perfect for its purpose; because steadiness of motion was a most essential quality in a dynamo, for removing from the commutator all vibration, and so preventing flashing. No doubt the author had already improved the machine very considerably with regard to economy; but even if it were not a perfect machine in economy of steam for the other applications that had been suggested, its great value for installations afloat was seen in its lightness and the very small space it occupied. Indeed even if it were extravagant in steam, the amount required to drive it was a very small fraction of the total consumption for propelling the ship; consequently any small saving effected in driving the dynamo was of no material consequence. Examples of great disregard for economy frequently occurred in the rough and ready donkey engines used at sea; there was perhaps very elaborate and perfect machinery on board for driving the ship, but the donkey, which was absorbing as

(Sir James N. Douglass.)

much steam as the electric installation and perhaps more, was very often of the rudest description and very extravagant in steam. The Members of the Institution had reason to congratulate the author on the very successful and perfect machine which he had brought before them.

Mr. W. Worby Beaumont asked whether this motor had been tried with steam pressures higher than that mentioned in the paper (page 485) of 92 lbs.; and if so whether the increase in the pressure was attended by anything like an increase in economy corresponding with that represented by the two figures given. With 61 lbs. pressure the steam used was stated to be 42 lbs. per electrical horse-power per hour, and with 92 lbs. pressure the consumption was reduced to 35·1 lbs. Did a similar fall in consumption occur with still higher pressures?

Mr. Gisbert Kapp said it was a full year since he first became acquainted with this engine and had an opportunity of testing it, which was a long time, considering the rapid developments that had taken place. The occasion was at the Newcastle exhibition, at which it had been his duty as one of the jury to be very critical, and to detect if possible any defects in the machines exhibited. But although having previously had an unfavourable opinion of this new contrivance, the tests then made had fully convinced him of its merits. The turbine there tested was not one of the triple kind. It was taken in the morning from its masonry pedestal in the exhibition to the works of Messrs. Clarke Chapman and Parsons in Gateshead, and was put under steam in the afternoon and kept running for four hours. The water consumed was carefully measured, and the electricity developed was also measured. From these measurements, which were as accurate as they could be when taken in an ordinary trial without elaborate preparations, the consumption of water was found to be a little over 50 lbs. per electrical horse-power per hour. The lights were exceedingly steady, the high-speed machine producing absolutely no vibration that could be seen, either in the machine itself or in the lights. There was however a sound in the lamp, something like

the humming of a bee or of a tuning-fork. This curious effect he had not noticed with any other dynamo, and he did not know whether it was peculiar to the machine, or whether it was simply an accidental effect at that trial; perhaps the author would state whether he had noticed it in any other case. The hum might have been either in the lamp itself or in the wires which led to it; but it was difficult to distinguish where it was. The lamp was in the photometer, and the box of the photometer might have acted as a kind of sounding board. As far as he could make out, the note of the hum heard at the lamp seemed to be about the same as that which he heard again when close to the dynamo.

With regard to the dynamo itself, the idea of running it at very high speed was excellent, because speed was much cheaper than iron or copper. But it was necessary to use some precautions. The author's magnets were made of cast-iron, which those who were accustomed to the old-fashioned dynamo considered a bad material; and when he first saw this dynamo he thought a much better machine might have been made of wrought-iron. But since then he had found out that it was perfectly right to make them of cast-iron, because if they had been made of wrought-iron they would have produced such a powerful field as to call forth in an excessive degree a certain magnetic effect which had lately been discovered by Professor Ewing and had received from him the name of hysteresis. According to modern views magnetisation was accompanied by a rotation of the molecules, and they appeared to have an aversion to being rotated, and if it was done too much they showed their dislike by getting hot. Therefore machines which were run very fast should not be very powerfully excited; and the author had accordingly done right in adopting such magnets as would not produce that effect. By having a cast-iron magnet and working in a fairly weak field, the heating effect which troubled very many dynamos was avoided. The arrangement of the armature winding was also a good one. The author had adopted what was usually known as the drum-winding, in which there was very little self-induction; and hence it was found that there was no sparking at the commutator, as had been pointed out by Sir James Douglass (page 495).

Mr. William Schönheyder understood the object of the bearing shown in Fig. 6, Plate 87, was to allow the spindle of the turbine to centre itself about its own axis of mass, which did not necessarily coincide with the geometrical centre of the mass. In that respect the spindle when running at a high speed was trying to do the same thing as a spinning-top, and it seemed to him that it might be looked upon as an eccentric revolving round a central axis; therefore the rotation must be continually throwing the journal from side to side and from top to bottom, once in every revolution, to a very small extent, which must result in giving the bearing a series of blows at the rate of 18,000 per minute, or whatever the number of revolutions might be. Those blows were taken up in the bearing by the friction of the washers one against another; and it appeared to him that this must be very much to the detriment of the bearing. That it ran well and satisfactorily might be due to the fact that it was really in balance, or very little out of balance, and that the lubrication was so good that no harm took place. But it seemed to him that the proper way of making the bearing would be to cause the whole of the washers to revolve with the spindle, making it of course suitably smaller, and to surround them outside with a cylindrical steel casing or sleeve, which should also revolve with the spindle and would then form the bearing; the spindle would thus be able to knock the washers to one side or the other within the casing, so that the centre of the mass would ultimately coincide with the centre of the outside casing or sleeve which formed the bearing.

Mr. Benjamin A. Dobson, Member of Council, said that, being somewhat familiar with high-speed bearings, he had had his admiration first awakened for this machine by an examination of the beautiful device for overcoming the practical difficulty that arose in making the mass of the turbine revolve at the high speed at which it was driven. A weight of only two grains at the extremity of the largest diameter in the triple compound turbine would represent at the speed at which it revolved a centrifugal force giving a blow of $2\frac{1}{2}$ lbs. up and down and sideways in each revolution; and it was hardly practicable to construct any shaft of that diameter without its being

at least two grains out of balance. Even so small a want of balance would be sufficient at such a high speed to cause an immediate wear in the bearing, supposing it were a hard and fast bearing such as was ordinarily used for lower speeds. First it would wear at the bottom, because in addition to the friction of the rotation there was the weight of the turbine itself. As soon as there was the slightest degree of wear at the bottom, there would be an up and down motion which would gradually wear the bearing elliptical. That would have proved an absolute bar to the employment of this machine, if it had not been for the author's device; because the amount of clearance was so little between the revolving blades on the turbine and the stationary guide-blades in the casing that a very trifling amount of play, such as would hardly be considered appreciable in ordinary machinery, would be sufficient to cause contact all round and thereby make the machine impracticable. The finding of the centre of gyration, or rather allowing the turbine itself to find its own centre of gyration, was a well-known device in other branches of mechanics: as in the instance of the centrifugal hydro-extractor, where a mass very much out of balance was allowed to find its own centre of gyration; the faster it ran, the more steadily did it revolve and the less was the vibration. Another illustration was to be found in the spindles of spinning machinery, which had to run at about 10,000 or 11,000 revolutions per minute; they were made of hardened and tempered steel, and although they were of very small dimensions, the outside diameter of the largest portion or driving whorl being perhaps not more than 1¼ inch, it was found impracticable to run them at that speed in what might be called a hard and fast bearing. They were therefore run with some elastic substance surrounding the bearing: either steel springs, or hemp, or cork, or india-rubber, which last however was of course objectionable in consequence of being deteriorated by the oil. In fact any elastic substance was sufficient to absorb the vibration, and permit of absolutely steady running. The washers forming the bearing described in the paper had a very small difference of diameter, which allowed the turbine a free vibration of that amount; but at the high speed at which it was running of 10,000 or 12,000 revolutions a minute or upwards it was obvious that it

(Mr. Benjamin A. Dobson.)

would be impossible for that vibration to occur in its entirety in each revolution. The object of the device was to neutralise the tremor by allowing a slightly eccentric motion to the bearing itself; this was divided amongst the two sets of washers; and as the lubrication was constant and the oil was continually pouring abundantly over the bearings, the amount of wear and tear was very slight indeed. The object he presumed of the spring which pressed the washers together was to put sufficient friction upon them for overcoming the difference of equilibrium that might exist initially in the turbine when beginning to rotate at a low speed. If the spring was strong enough to overcome that, it was evident there would be no shock, because the same friction would be equal to the action of the smaller vibration at the higher speed. Having himself made a number of experiments with regard to the bearings of spindles running at high speeds, he had found that as a rule, with hard and fast bearings, if it was a spindle in extension —that is, supported only at one end and at the middle, with half its length projecting unsupported — there was a particular speed, varying according to the weight and diameter and overhanging length of the spindle, at which it was impracticable to run the spindle when there was the slightest want of equilibrium, in consequence of its excessive vibration. When this was found to be the case, it would very often be discovered that on increasing the speed the vibration would in a great degree disappear. It was indispensable with that class of bearings that there must be a high speed; because if the speed was slow, and the want of equilibrium was sufficient, there was at each revolution a shock which it was necessary to avoid. In the small spindles with which he was himself accustomed to deal these phenomena were very remarkable indeed. In some instances an addition of 1,000 revolutions per minute would alter a spindle running badly to a spindle which ran very well. He had not been able to discover that there was any limit to the extreme of speed; having gone up to 17,000 and 18,000 revolutions a minute, which was as much as could well be measured, he had not found that there had been any change after say 15,000 revolutions had been passed. But from 4,000 up to 8,000 revolutions per minute, according to the make and weight of the spindle, the diameter of its bearings, and

general conditions, there was a very remarkable divergence of behaviour, so much so that it was impracticable to decide upon the exact proportions of the spindle; and therefore every one who had to do with such spindles had been obliged to come to the practical adoption of some sort of elastic bearing for them. He should be very glad to know if any of the Members had had any experience in that respect, and whether they could define the law which governed the vibration in those particular cases. Although he had not yet had the pleasure of seeing this machine at work, he was convinced from the description which had been given, and from an examination of the elastic bearing, that it would run, as Sir James Douglass had said, absolutely without vibration and noiselessly. The combination of the suction-fan, the leather diaphragm, the spiral spring, and the air-pipe as a centrifugal governor, he considered to be one of the most ingenious things it had been his good fortune to see; and he was sure it would require long and careful study before engineers could devise anything that would much surpass this compound turbine engine.

Mr. Henry Davey remembered that at the time of the description being given to this Institution (Proceedings 1882, page 519) of De Laval's centrifugal separator for separating cream from milk, which ran at a very high speed, there was considerable difficulty with the bearings on account of the gyratory motion. Since that time however the bearings had been modified by surrounding the upper bearing with an elastic band instead of a rigid collar; and this modification had made the machine perfect. The accidents that used to happen to it never happened now, owing to that particular expedient, on which Mr. Dobson had rightly insisted (page 499), of surrounding the bearings with an elastic substance.

In continuation of his previous remarks in Dublin (page 489) with regard to the economy of the compound steam turbine, although it might not be a very economical machine, yet for so small an engine he thought it was fairly economical. In the author's previous reply (page 492) only between 50 and 60 per cent. had been given as the actual efficiency of the motor; but the mechanical

(Mr. Henry Davey.)
efficiency must be high, and assuming it as he had previously done to be 80 per cent., while that of the dynamo was 95 per cent., the lowest steam consumption of 35·1 lbs. given in the paper (page 485) would with these percentages lead to a total mechanical efficiency as already mentioned (page 489) of $26\frac{1}{2}$ lbs. of steam per indicated horse-power per hour, which for a small non-condensing engine like this he thought was a good result; and he believed a better result would be obtained from the triple-expansion form of the turbine. The electrical efficiency given by the author for the motor was probably as high as that of many of the small reciprocating engines and dynamos; and this should be borne in mind in considering the merits of the machine.

Mr. Mark H. Robinson believed that for electric lighting on shipboard economy was now highly valued by the Admiralty, who had formed a sort of scale of allowances for comparing the cost of electric lighting apparatus, based upon the different rates of steam consumption guaranteed by the makers, with the object of ensuring that lowness in first cost should not alone be considered. He took the opportunity of expressing his own admiration of the ingenuity and beauty of the machine described in the paper.

Mr. J. Macfarlane Gray mentioned that a marine engineer who had just returned from running a Yarrow torpedo boat in Chinese waters had nothing but admiration for the turbo-electric generator which was fitted on board, so little trouble had it given him. Of the quantity of steam consumed he was unable to speak, as it had not been measured; but he had not missed it, as the boiler gave plenty.

Mr. John G. Mair enquired what was the efficiency of the steam turbine itself, independent of the dynamo which it drove. It appeared to him that it was a machine which ought to possess an exceedingly high efficiency, because practically there was nothing whatever in it to absorb power, except the friction of the bearings.

He also asked whether in designing and making the steam turbines they were made applicable for all pressures, so that the best results could be obtained alike with all steam pressures and at all speeds. In turbines for water power the best result could be obtained only at one particular speed and with one particular pressure or head of water for each individual turbine. If the same was the case with the steam turbine, what loss of efficiency was to be expected from a reduction in the pressure or in the speed?

Mr. Arthur Paget, Vice-President, in explanation of the reason why the revolution of a badly balanced and therefore oscillating body might in some cases absorb more power at a lower speed and less at a higher, referred to a former discussion upon a paper read before this Institution on thrashing machines (Proceedings 1881, page 401), in which it had been pointed out by Mr. Pendred that the rate of oscillation of the reciprocating shoes or sieves under the straw-shakers ought to be synchronous with that due to the length of their hangers considered as pendulums; and if they were driven at any other than that speed, either slower or faster, more power would be required. If that principle were applied to the spindles referred to by Mr. Dobson (page 500), which were not perfectly in balance, he thought it would be found that the least power would be absorbed in driving them when the speed of revolution was made to correspond with the speed of oscillation of the extremely short pendulum which would represent the minute want of balance in the spindles.

The present paper was the second in which there had been brought before the Institution a high-speed engine of great efficiency and beautiful working as far as lubrication went. The honour and credit of its merit in this last respect he thought might fairly be said to belong to this Institution; for the lubrication of the engine now described appeared to depend entirely upon the oil not being fed in a niggardly manner, drop by drop, but being actually driven through the bearings by the feeding screw. Similarly in regard to his spherical engine it had been properly stated by Mr. Tower (Proceedings 1885, page 115) that its success was mainly due to the same cause, namely that the oil was not dropped in with a

(Mr. Arthur Paget.)

sparing hand, but was forced abundantly through the bearings. No doubt the author of the present paper would himself be the first to acknowledge that the experiments of the Research Committee of the Institution on the friction of bearings at high speeds had led him to adopt the admirable plan of forcing oil abundantly through his bearings; and probably it might not unfairly be said that this ample lubrication had contributed materially to the success of his steam turbine and dynamo.

Mr. W. Silver Hall mentioned that some time ago he had met with a very efficient kind of lubricator, consisting of a close-topped box, containing a sort of stiff grease. By screwing down the top of the box from time to time, a little of the grease was forced into the bearing; and it was impossible for the grease to be thrown out from the bearing through the oil hole, because that oil hole was sealed by the screwed cover. That lubricator, which had been used by himself for ordinary purposes, would act he believed in keeping a bearing cool in cases where any ordinary lubricator, which would permit the oil or grease to flow in and out, would fail. The only way in which the grease could escape with that lubricator was of course endways along the bearing; and so in the bearing described in the paper, the oil appeared to be continuously held to the bearing, and could not get away except by traversing right over its whole length.

Professor George Forbes was glad to have this opportunity of testifying to the feeling with which electrical engineers regarded the beautiful engine brought before them by the author. Most of them he believed would agree that but few substantial advances in connection with dynamo electric machinery had taken place during the last fifteen years. Since the invention of the dynamo machine by M. Gramme he thought the three most important advances which had been made and which would always be remembered in connection with dynamo electric machinery were the system of distribution by transformers by Gaulard and Gibbs, the alternating-current motor of Tesla and Ferraris, and now the turbo-electric

generator of Mr. Parsons. Most of the other improvements in dynamo electric machinery had been purely in matters of proportion; but in those three inventions there had been real brain-work, and in none of them was there such an amount of original invention and brain-work as in the turbo-electric generator. It was true this was more the case in the mechanical parts than in the electrical parts; but each part displayed distinct inventive ability, which required also considerable courage for its development into practical realisation. Whether in the bearings, or in the electric governing, or in the various other parts, it was a new contrivance altogether. From an electrical point of view he was struck with the beauty of the dynamo machine and of the electric governing; the latter he thought was more perfect in this than in any other arrangement he had ever met with. Having watched the machine carefully in a considerable number of places where it had been put to work, he had been much struck in every case with the perfection of the mechanical details. A few months ago he had had the opportunity on board the "City of Berlin" of spending a great part of the voyage from New York in company with Mr. Webb, the engineer of that steamer, on which two of these turbo-electric generators were in use; and what had struck him most, in comparing this vessel with the other Atlantic liners on which considerable attention was required by the dynamo electric machinery, was the almost total absence of attention in connection with the running of the turbo-electric generator during the whole nine or ten days of the voyage. One little accident happened to one of the turbines during the voyage, but it was a thing which might have happened to any other piece of machinery. The working generally was extremely perfect, requiring so very little attention, and was satisfactory to every one who had to deal with it.

The theory of the compound steam turbine presented many points of interest. One especially was that, when the engine was first introduced, it was thought by some that there would be a great loss of power from the friction of the steam passing through the series of turbines; whereas one of the most beautiful things about it was the almost total absence of any loss of power from that cause.

(Professor George Forbes.)

The greater the friction in its passage through the turbines, the drier was the steam and the greater was the efficiency of the whole apparatus; the heat developed by the friction was being utilised all the time in making the machine more perfect.

With reference to accidents, it would of course sometimes happen that the bearings would wear, and that collisions would consequently occur between the blades on the spindle and those in the casing, resulting in their mutual destruction; and he wished to know whether in actual practice such accidents had been found to be of frequent occurrence, or only rare. The washers could of course be replaced pretty readily; any information about the wear of the spindle would be interesting.

With regard to economy, he had not had the good fortune to be able to make any tests on the consumption of steam; but he thought the statements made in the paper might be accepted as being accurate. The economy was certainly extremely good already, though the engine worked non-condensing; and all were looking forward to the probability that when the author introduced condensing, as he believed he intended to do, there would be a great step in advance, and this machine would probably be as economical as any means now known of generating electricity: for it must always be remembered that the high speed of this dynamo machine tended to make it the most economical and efficient of any of the contrivances for the development of electrical energy. There was one defect however in regard to the application of the turbo-electric generator to central station work, namely the noise which it created. It was certainly a veritable siren; and it became a question how far its noise could be deadened, so that it might be possible to introduce it into the centre of a town without its being a nuisance. This object he believed could be accomplished thoroughly by proper means. In the installation at Lincoln's Inn, London, the dynamo room was lined with felt, and by that means the noise in the room was completely shut off from the street. But the noise was carried on by the steam pipes into the boiler room, where it came out. It had however been suggested, and it was probably true, that the noise would be much diminished by having the pipes bent

where they passed from the dynamo room into the boiler room. At any rate he felt great confidence that the question of noise could be dealt with efficiently in some way or other; and that was the chief objection he had seen to the machine.

Beyond the uses to which it had been at present put, he thought he saw a great field for its future development, not only by the condensation of the steam, but also by the possibility of its use as an alternating-current dynamo machine. At the present time alternating - current dynamo machines constituted the most important means of distributing electricity from central stations; and until quite lately at any rate those machines had been very imperfect indeed. The class of machine with only two poles was far more perfect than that with a great number of poles as ordinarily constructed. It had occurred to him some time ago to suggest that the high speed of rotation of the turbo-electric generator rendered it extremely easy to convert it into an alternating-current dynamo, by putting two insulated rings over the commutator, connecting one with one commutator bar and the other with the opposite commutator bar. That experiment had lately been tried by the author, and he had found that the machine worked splendidly as an alternating-current dynamo in that way; and the heating of the pole pieces, which had been expected to prove a serious obstacle, was not so at all. When worked in that way it seemed to him to be the most perfect kind of alternating-current dynamo machine in existence. It ran at 8,000 revolutions per minute, making therefore 16,000 reversals; and it so happened that this number of alternations was just what had been found in practically successful alternating dynamos to be the best speed of alternation. Consequently for alternating currents the turbo-electric generator seemed likely to become in future the best of all.

Mr. Joseph Richmond asked what was the greatest number of lamps lighted by any one of the turbo-electric generators. It had been stated that there was a loss of only 5 per cent. between the motor and the dynamo, but that the efficiency of the motor was only between 50 and 60 per cent.; thus showing a total loss of about 50

(Mr. Joseph-Richmond.)
per cent. Would the author say what he considered to be the actual efficiency of the whole arrangement, in the relation of coal burnt to candle-power? There was a great future he considered for electric lighting, but at present there was competition to be met; and if gas was to be superseded for the lighting of parishes, large warehouses, stations, &c., it would be necessary to go to the root of the cost, which would be the consumption of coal per candle-power. He should also like to know what was considered to be the wear and tear of the whole of the machinery. At an establishment with which he was associated, where there was a quantity of machinery and one of the turbo-electric generators was used, he intended to give it a separate boiler to itself, and to weigh the coal out to the boiler, and take account of the number of lights in relation to the quantity of coal burnt. Meanwhile he certainly congratulated the author upon the ingenuity of the whole apparatus; every engineer would admit that the governor of the motor was as clever a piece of mechanism as had been seen for many a long day.

Mr. John P. Fearfield asked whether the author had ascertained from experience what was the relative efficiency of the compound steam turbine between wide ranges of load, as compared with that of an ordinary reciprocating compound steam engine. Could a compound steam turbine of 50 horse-power work as economically as a reciprocating compound engine of the same power with loads varying from 5 to 50 horse-power? If the efficiency of its working was limited to a constant load and a uniform speed, as when the dynamo was supplying a constant current with constant pressure, it could only be used with anything like economy either in charging accumulators, or for large arc lamps which required a constant current or one varying only very slightly. In many electric lighting installations at the present time, as he believed would be the case with most of them in the immediate future, motors were required that would work economically between wide variations of load. For electric lighting in a large club or factory or warehouse, or on ship-board for search-lights, or in a light-house, or wherever the whole light was constantly wanted, he could understand that the turbo-

electric generator might be very economical; it was no doubt an admirable piece of machinery. But those were exceptional cases. What the public required was a light that could be turned on and off just like gas, which could be stored in a large gasholder and supplied as required. It would not do to have dynamos driven by engines that would be far from economical when working under only a portion of their nominal load. In designing a plant for five hundred lights, there must be arrangements for working only ten or other small number; and the coal bill would be running up unduly, if the motor was not so designed as to bear great variations in load with a fair amount of economy. How economically the best compound engines of the present day were working was well known; but as yet he was not aware of any high-speed engines, directly coupled to generators, that were working anything like as economically with varying loads. Not that they did not work economically with one fixed load; but it was the varying load that interfered with their economy.

In regard to the number of lamps that any dynamo would drive, this depended a great deal upon the kind of lamps employed. The mere number of lamps was not a test of the work done by the dynamo; what was wanted to be ascertained was the amount of the current and the voltage.

Mr. Jeremiah Head, Past-President, was glad to have the opportunity of saying how much he admired this beautiful piece of mechanism. Although the originality and ingenuity displayed in the design and execution of the various details must call forth admiration, yet it must be borne in mind that after all the main peculiarity of the engine was the enormous speed at which it ran. Twenty years ago no one knew of anything more than about 300 revolutions per minute in practical running. Then came the Brotherhood three-cylinder engine, and afterwards the Parsons engine made at Leeds, which brought the possible number of revolutions up to perhaps 1,200 at the utmost. But here was a machine that went at 12,000 revolutions, and occasionally even at 18,000. This was an enormous stride in the way of velocity beyond anything that had been done before; and that fact should

(Mr. Jeremiah Head.)
be kept well in mind. Of course so high a speed meant great power in a small space and for a small weight. Without having worked out any calculation, he ventured to think the compound steam turbine gave a greater power for its weight than any other kind of engine known. To engineers this afforded matter for much thought, because there were so many instances in the arts generally in which great power was wanted without great weight. One that occurred to him at the moment was aerial navigation. It had always been said for a long time past that it would be impossible to propel machines in the air because of the great weight of any engine which would be required to do it. If yet further progress could be made in the direction taken by the author, there was no telling what might be arrived at. It was rather a curious thing that the first steam-engine of which there was any historical record—namely that by Hero of Alexandria—had also been a turbine; and here, in the latest invention, the same principle had been adopted: the only difference being that the former engine must have been an exceedingly wasteful one, while the present appeared to be fairly economical. He was not at all sure that the economy would not very soon be improved; because, if a condenser were added to it, this alone would produce some economy. But whether this addition were made or not, 90 lbs. steam pressure seemed to him to be absurdly low for such an engine. In the very town where it was constructed, Gateshead, he had seen only a few days ago a Perkins engine working at 400 lbs. pressure at the works of Messrs. Hawks Crawshay and Sons; the steam gauge showed 400 lbs. per square inch, and the engine had been working for a long time with 24 expansions, and, as far as all appearances went, with success to itself and perfect safety to the boiler. He could see no reason why the author should not adopt the same principle for the steam turbine, and try a much higher pressure with more expansion; and perhaps he would see his way to do so.

An engine so distinctly novel had set him thinking in various ways. There were many places where not only was it important to have extreme lightness in the motor, in order to get as much

power as possible for the least weight, but where it was also most important to avoid having to carry great weights in the shape of fuel and water. For instance there was the case of the steam plough working in a field, to which both the coal and the water had to be carried. In a good boiler 1 lb. of coal would evaporate about 10 lbs. of water; so that the 1 lb. of coal taken to any spot really meant a total weight of 11 lbs. to be carried thither. There were many other circumstances conceivable under which it was of the utmost importance to avoid taking such large weights for keeping up motive power. The only idea that occurred to him for meeting such cases—and possibly it might be applicable to the steam turbine—was to use petroleum, which possessed about twice the evaporative power of an equal weight of coal. Therefore there was an advantage in burning petroleum under such circumstances, instead of coal. But if the petroleum could be burnt in the engine itself, as was already being done in the cylinder of the petroleum engine, it would save the water altogether: that is, it would save carrying the 10 lbs. of water for the 1 lb. of coal, and therefore the total weight of petroleum required to be carried would be reduced to something like one-twentieth of the present weight of coal and water together. Whether the products of combustion from petroleum could be applied to such a machine as the compound steam turbine he did not know; it would require a great deal more thinking out, but it did not appear impossible; and the sight of such an advance as was shown by this machine, beyond anything that had previously been done, had naturally set him thinking whether yet further progress might not be made in the same direction, so as to get enormously more power than had ever been thought of before for a given weight of machinery, and also very much less weight of coal and water used for it.

Mr. W. D. Scott-Moncrieff noticed that in the previous discussion, in answer to observations made by Mr. John Sturgeon respecting the use of compressed air, the author had remarked (page 491) that, compressed air being heavier than steam, the speed of its outflow through the turbine would more nearly agree with the

(Mr. W. D. Scott-Moncrieff.)

speed of the blades, and the resulting efficiency would consequently be rather higher. He gathered therefore that the author believed the compound turbine was suitable for the employment of compressed air as a motive power under conditions of considerable economy. But he then went on to say that the formation of ice in the passages between the blades, due to the expansion of the air, would probably be prevented if the air was heated to 180° or 200°. No doubt the heating of the air in the case of the compound turbine would result in an economy equal to that resulting from the heating of the air for use in a reciprocating engine. But he would take the opportunity of pointing out that, if the air was to be used expansively in the compound turbine, probably the same rule would apply as that which to a certain extent he thought he had discovered in the use of compressed air in reciprocating engines: namely that the excessive loss of heat which led to the formation of ice in the working parts, especially at the points of exhaust, was really due, not so much to the absorption of the heat which was the mechanical equivalent of the work done in the cylinder, as to the fact of that absorption being further augmented by the loss which subsequently arose from the sudden expansion of the air, doing useless work amongst its own particles at the point of exhaust. In other words, the difficulties arising from the use of compressed air at ordinary atmospheric temperatures arose not from expanding the air too much, but from expanding it too little. He had discovered that, as soon as the expansion was carried to a point at which the residual pressure at the moment of exhaust was the pressure of the atmosphere, all difficulties with regard to freezing ceased: so that in an ordinary reciprocating engine the amount of heat which was absorbed as the equivalent of the work done in the cylinder would not then produce sufficient cold to give trouble in the form of ice. As a matter of fact it gave trouble only when the air, having been already deprived of the heat due to the work done, was allowed to escape at a pressure considerably above that of the atmosphere. Possibly the same rule might apply to the use of compressed air in the author's beautiful compound turbine.

Mr. James Stabler thought that, taking into account the relative pressure and velocity of the steam in its passage along the circumference of the revolving spindle in the compound turbine, the proper form for the outline of the spindle would be an adiabatic curve. He agreed with Mr. Head (page 510) that a higher pressure of steam might be used advantageously; but the highest pressure of say 300 lbs. per square inch should be admitted he thought upon the largest diameter and shortest length of the spindle, and should thence be expanded in a succession of steps, each of smaller diameter and longer length than its predecessor, until it was finally exhausted from the smallest diameter and longest length of the spindle. By thus reversing the progression of the diameters from that followed in the triple compound turbine described in the paper, the steam, as it became reduced in pressure and expanded in volume, would be enabled he considered to give off continuously its full effect. In that way he believed the whole power of the steam might be taken up. The want of economy which had resulted in the failure of the many rotary engines brought out during the last fifty years had been the consequence in his opinion, not so much of leakage or of other defects in construction, as of neglect of the diminishing velocity of the steam in passing through; and unless this point was duly attended to, it seemed clear to him that it was impossible to obtain entire economy in the use of the steam supply.

Mr. P. W. Willans, referring to the intention expressed by Mr. Richmond (page 508) of weighing out the coal to the compound steam turbine, pointed out that such an ordeal was not always satisfactory, because it confounded the efficiency of the engine with that of the boiler; and he would therefore suggest weighing out the water instead of the coal, which he thought would give more useful information.

As to making a motor which would be equally efficient at all powers (page 508), that he believed would be exceedingly difficult to do with any engine, until an arrangement could be devised whereby its size could be reduced as the lights were turned off. These

(Mr. P. W. Willans.)
conditions could most nearly be approached for electric-lighting work by subdividing the power and using several motors.

With regard to steam consumption, the economy of the compound turbine with 61 lbs. steam pressure seemed remarkably good (page 485); but 35 lbs. of water per electrical horse-power per hour for 92 lbs. pressure did not seem to him to be a good result. At his own works with 92 lbs. steam pressure he was now getting an electrical horse-power for rather less than 30 lbs. of water per hour. It would be interesting to know what would happen with the turbine when much higher pressures were used; he supposed that by lengthening the engine probably about the same efficiency would be arrived at in the end. The same result he imagined would probably follow from condensing trials, for which also he supposed the turbine would have to be lengthened a good deal.

Friction had been spoken of by Professor Forbes (page 505) as having been expected to prove the main source of loss in the compound turbine. It appeared to himself doubtful whether there would be such a great amount of friction; but even if there were, it further seemed improbable that this would all come back in the shape of power: inasmuch as any heat caused by friction would not be quite so usefully employed in the turbine as it was in the boiler, because in the turbine it would be employed in re-boiling at a later stage the water that was formed during the earlier stages of expansion, re-evaporating it at a low pressure and thus making low-pressure steam, just as a steam-jacket would do when going beyond its proper function. The main loss must he thought be that due to leakage, the limit to the economy of such a machine being fixed by the amount of clearance which for practical reasons it was necessary to allow.

The Hon. Charles A. Parsons, referring to the mention made by the Chairman of the mode of perfecting the finish of these machines by grinding the spindles, said it was difficult to get a sufficiently true spindle by merely turning it in a lathe. All the spindles for the compound turbines were ground by an excellent automatic grinding machine made by Messrs. Smith and Coventry, which

gave almost absolute truth. When the spindles came off the lathe, and were subjected to the grinding machine, they appeared to be three-cornered and all kinds of shapes; but the grinding machine gave them a wonderfully true finish in the end. It had also been found difficult to get the bore of the casing absolutely true. When the spindle had been turned and ground as nearly true as possible, and had been covered with rings of blades, the complete moving part was then ground into the case with fine emery; and by that means they could run with a clearance of only about 1–64th of an inch all round, and sometimes rather less. There had been some difficulty from the expansion of the metal by the heat of the steam passing through; and the parts were often ground first cold with small clearance, and were also ground in again when the cylinder was hot, so as to get as near a fit as possible in running. Whatever clearance there was initially did not increase, because it was found in practice that in consequence of the continuous lubrication the wear of the bearings was almost nil; in fact in some instances after two years' almost continuous work the wear did not measure 1–500th of an inch in diameter. In the larger turbine, of 50 horse-power, there had been a certain amount of abrasion due to the knocking action which had been mentioned; and this had been got over by surrounding the steel washers with steel liners, instead of allowing their sharp edges to bear directly on the cast-iron.

With regard to the apparent discrepancy in page 485 between the consumption of 42 lbs. of water with 61 lbs. pressure of steam, and 35·1 lbs. of water with 92 lbs. pressure, the difference arose from the two tests not having been made on the same machine. The 42 lbs. consumption was obtained with a 400 ampère machine; it was larger, and the speed of the blades was rather higher, more nearly approaching the theoretical speed at which they should run for maximum efficiency. The 35·1 lbs. consumption was obtained with a 300 ampère machine, which was not quite so perfect. In answer to Mr. Beaumont's enquiry (page 496), the economy was increased to a considerable extent when the pressure was raised, but at present the increase in economy was not in the same proportion as the rise of pressure should theoretically give: comparatively better

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results were obtained at lower pressures than at higher; in other words the consumption of steam as compared with that of a perfect engine was less at low pressures than at high pressures. But he hoped to get equally good results in the course of time.

The humming which had been observed by Mr. Kapp in the lamp at the works in Gateshead (pages 496–7) was due he thought to the fact that it was a 16-candle lamp, and was worked by a machine with a ten-part commutator. With this small number of sections there was a considerable variation of electromotive force during a revolution, which caused some molecular disturbance in the filament of the lamp. A much louder noise was produced by the same current when passing through iron wire resistance coils. The machines were now made with a fifteen or twenty-segment commutator, whereby the variation in electromotive force was much diminished; and the hum was not then audible.

For the magnets (page 497) wrought-iron had been tried, but it was not successful; there was not enough residual magnetism to start the dynamo. Cast-iron retained considerably more magnetism, gave as much power as was wanted, and was cheaper.

The steel washers forming the bearings of the turbine differed somewhat in principle from the india-rubber ring used in the milk-separating machines (page 501). A spring bearing, tending to centre the spindle, was not alone sufficient. The india-rubber ring possessed a small amount of viscosity as well as resilience; its elasticity was equivalent to a spring pressing the axis into the centre from all sides, and thereby helping to steady its running. But any such spring had of course a certain amount of reciprocity in relation to the vibrations of the spindle; and a spring which he had tried had been found not to answer, because at certain speeds, at which the rate of rotation of the spindle was a multiple of the period of vibration of the spring, so great a vibration had been set up that it caused the blades to foul. To prevent this a considerable amount of frictional resistance was required, which had now been obtained with the washers. Another point, which was perhaps rather interesting from a scientific point of view, was that the body of the steel spindle itself of say 4 inches

diameter, if it were running in fixed bearings at 10,000 revolutions per minute, would be very apt to "whip" or bend; the whole spindle would bend bodily, and its mass revolving eccentrically about the fixed bearings would produce intense pressure on the bearings, and would cause them to heat. The washer bearing combined the resilience due to the spindle itself with the frictional resistance of the washers to any motion. The same principle held good here as with the gyroscope, that when pressure was applied in one direction it produced a motion at right angles, and so brought the spindle back to its central position, involving a minimum of motion to the washers.

With regard to abrasion and knocking, the film of oil always surrounding the bearing entirely prevented abrasion. At certain speeds these machines ran a great deal more quietly than at others; it was found that below 8,000 revolutions per minute the noise was much diminished; it was not observed nearly so much, and in all except the very small sizes this was fixed as the limit of speed. The machines at Lincoln's Inn, mentioned by Professor Forbes (page 506), were running at a little over 9,000, between 9,000 and 9,500 revolutions per minute; and for that reason they caused more noise than usual.

As to the comparative loss of efficiency in the compound turbine with a reduction in the steam pressure or in the speed (page 508), he was not aware what was the duty to expect from compound engines under varying loads, or what their consumption was at half loads; but from a theoretical point of view he should expect the same comparative average efficiency from the compound turbine as from compound engines. If the maximum efficiency was identical in the two cases, the average efficiency would be about the same, or perhaps rather better in the turbine because it had so much less friction; the frictional resistance of the spindle bearings did not amount to more than 2 per cent. of the power developed. The areas of the passage-ways between the blades were of course fixed, increasing in size in the successive turbines; they corresponded directly with the areas of the cylinders in a compound engine, and he thought therefore the average efficiency should be about the same.

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The idea of continuous oiling had probably been borrowed, as mentioned by Mr. Paget (page 503), from the papers read at this Institution; but as he had adopted the principle in the high-speed engines he had designed and made eight years ago, he could not give a definite answer on this point. He had at that time proved the great reduction of friction which resulted from continuous lubrication. He had found practically that, in such a small bearing running at so high a speed, the heat generated in the bearing was more than could be carried away by radiation, and that the flow of oil over the surface was a great preventive of local heating and of consequent seizing in the bearing. It would run for a short time without continuous lubrication; but the bearings were sure to get into bad order, and they would be certain to seize eventually.

Breakages of the blades, about which Professor Forbes had enquired (page 506), had in a few individual cases been a source of trouble. The blades had in some cases been made too high in proportion to their breadth, and rather weak. This had now been remedied, and he thought there would be no more trouble with them. The larger turbines of 50 horse-power ran at about 6,500 revolutions per minute, and at that speed the velocity of the blades was about the theoretical velocity for best efficiency. As with the water turbine, there were certain rather wide limits between which a high efficiency was obtained, differing little from the maximum efficiency; the theoretical velocity of the blades for best efficiency was about 60 or 70 per cent. of the velocity of the steam at its outflow from the guide blades. The principal loss in the steam turbine was due to leakage, which he hoped to diminish greatly by better workmanship and other means.

In reply to Mr. Richmond's enquiry (page 507), the greatest number of lamps lighted by any one of the turbo-electric generators had been about 550.

He was greatly indebted to Mr. Head for his observations (pages 510–11), which were very suggestive indeed; and he hoped that some of them might be realized. In regard to aerial navigation and the application of petroleum to work the compound turbine, he would say that the matter was one of great interest.

A valuable piece of information about the formation of ice had been contributed by Mr. Scott-Moncrieff (page 512). He had not himself been aware previously that ice was not formed so much when the air was properly expanded continuously. It seemed difficult to account for such a result, and he should have thought that, the more work was taken out of the air, the more ice would be formed: if the temperature was more lowered by expansion in the engine, it seemed natural to expect that more of the water which was held in suspension in the air would be formed into ice. The statement now made he hoped would be found to hold good, because it was a great disadvantage to have to heat the air, even though it did give a slight increase of volume and efficiency. The compound turbine ought to be a very good motor indeed for working with compressed air, especially in connection with the distribution of power by compressed air in the manner indicated by Mr. Sturgeon in the previous discussion (pages 487–8).

On board the "City of Berlin" (page 505), which was the first large ship that had been lit with electric lights by this means, there were 420 glow lamps, and two generators, each capable of maintaining the whole number of lamps. A large number of the turbos were now at work, amounting in all he thought to a little over 3,000 electrical horse-power.

In regard to the application of the turbo-electric generator to central station lighting, he could fully endorse the remarks made by Professor Forbes (page 507): the dynamo with its very high efficiency and high speed of rotation gave the most suitable number of reversals, namely 16,000 per minute. The turbo motor, possessing fair economy in the smaller sizes and high economy in the larger, would when fully developed as a condensing engine possess this quality in a more remarkable degree than had perhaps ever been anticipated in relation to any steam engine.

The Chairman said this machine was no doubt a remarkable development from the original rotary engine referred to by Mr. Head as having been made by an ancient philosopher, in which the steam was wastefully discharged direct from the revolving boiler into the

(Mr. Charles Cochrane.)

atmosphere, and simply by its reaction turned the apparatus round. Passing on from that merely scientific toy, there followed the windmill with its extravagant waste of air blowing through its vanes, doing very little efficient work compared with the volume of air that passed through it. And now came the wonderful apparatus described by the author, by which almost the duty of a triple-expansion engine was done, or seemed likely to be done; for while the steam was at present expanded down to atmospheric pressure only, the hope was expressed that condensing would be brought to bear upon it. Already at the Newcastle exhibition last year the clearance he understood had been reduced from 1–32nd of an inch to only half as much or 0·015 inch, and by that little alteration alone 50 per cent. of the leakage had been saved. Therefore he could not help thinking that, when the work was put together in the improved way which the author had now indicated, the bulk of the remaining leakage would be further got rid of; and by-and-bye a perfect machine would be produced of a kind which hitherto had not been in general operation, although there had been some rough and rude examples in the past. The Members he was sure would gladly join him in according a hearty vote of thanks to Mr. Parsons for his excellent paper.

Professor Ryan wrote that he regarded the compound steam turbine as a novel and admirable invention, and a special boon to electrical engineers. The high speed necessary for efficiency in the turbine was eminently suitable for the dynamo also, because it permitted diminution in the size of the armature and consequently in its reactive influence. The compound turbine completely surmounted the difficulty of varying temperature in the cylinder, because a permanent distribution of heat was attained; and owing to conduction the steam found itself for the most part in contact with metal which must be hotter than itself. Fluid friction

was referred to in page 483, and it would appear to observers as if this might amount to something considerable. It was an important consideration however that, if one of these engines were adequately jacketed, the heat developed by the friction would for the most part be returned to the steam and therefore not be lost. It would be very interesting if the author could furnish a record of the rate at which heat was lost, under the circumstances, firstly of the turbine containing steam at rest, and secondly of steam passing through it at the usual speed. The size and shape of the machine would readily permit of such measurements.

Engineers and students of physical science in general would be greatly indebted to the author if he would furnish the results of some of the very many experiments which he had conducted in connection with this subject. The information given in the paper on the methods of testing was sufficient to stimulate curiosity without exactly satisfying it. In several cases the terse and significant language used by the author might have been amplified with advantage. In the paragraph about the efficiency of the dynamo (pages 484–5), where it was said that the losses had been ascertained by "observing the change of steam pressure required to maintain the speed constant," did these words imply a series of observations with different loads at constant speed? And if so, the tests being presumably meant to take place under practical conditions, was it to be inferred that in actual practice it was thought fit to vary the steam pressure with the load, rather than to alter the speed? No doubt many would be glad to learn also whether the commercial efficiency of the dynamo, which was recorded as 95 per cent., had been ascertained by independent measurement, or inferentially by estimating the aggregate losses previously referred to.

The triple-expansion analogy hinted at in page 483 was surely an accidental resemblance merely, and therefore delusive as an analogy. A conspicuous merit of the compound turbine was that it enabled continuous expansion of the steam to take place. Theoretically the machine should be conical in form, tapering gradually outwards from the apex where the steam entered. If the exigencies of practical construction necessitated breaks here and there, forming a stepped

(Professor Ryan.)

arrangement, the machine should not be characterised by what was after all a defect. In the reciprocating triple-expansion engine the successive cylinders were not concessions to convenience of manufacture, but were means whereby to diminish initial strains and ranges of temperature, and so to obtain specific advantage. The resemblance in form, he submitted, ought not to count for much.

DESCRIPTION OF THE RATHMINES AND RATHGAR TOWNSHIP WATER WORKS.

By Mr. ARTHUR W. N. TYRRELL, of London.

Locality.—The idea of controlling and utilizing the head waters of the River Dodder originated with the late Mr. Robert Mallet, who in 1846 was instructed by the Commissioners of Drainage for Ireland to "investigate the feasibility and conditions of constructing reservoirs on some part of the River Dodder, for the combined purposes of providing an unfailing and increased supply of water power to the mill-owners occupying the stream, and contingently of controlling the floods, which at frequently recurring intervals prove so destructive to property situated on its banks." After a lengthened investigation of the question, Mr. Mallet recommended the construction of a large impounding reservoir in the upper part of the Glenesmoel Valley, near the ancient burial ground of St. Anne's (marked on the plan, Plate 91), by an embankment 1,025 feet in length and rather more than 100 feet in height; the reservoir was to have a water surface of 142 acres, with a content of 227,843,645 cubic feet, and a drainage area of 6,070 acres. Nothing further however was done in the matter. Subsequently in 1860, when an improved supply of water for the city of Dublin was under consideration by Sir John Hawkshaw, the royal commissioner appointed to investigate the subject, Mr. Mallet brought forward a project for procuring the supply from the River Dodder. It was however rejected for two reasons:—firstly, that the quantity of water procurable from the district would not be sufficient for Dublin; and secondly, that, in order to obtain the quantity which it was stated the district would supply, it would be necessary to impound the whole of the water from the drainage area of 9½ square miles, about two-thirds of which is covered with peat, and excepting in very dry weather produces water more or less coloured thereby.

Projects for Water Supply.—In 1877 the supply of water to the Rathmines and Rathgar Township from the Grand Canal at Gallanstown being deemed unsatisfactory, a provisional agreement was arrived at between the Waterworks Committee of the Corporation of Dublin and the Rathmines and Rathgar Township Commissioners, by which the former body were to supply the township from the city mains with an average of 1,000,000 gallons of water daily for an annual payment of £2,281 5*s.* 0*d.*; and any further quantity up to 1,500,000 gallons daily at the rate of 1½*d.* per 1000 gallons. This agreement not being ratified, the Rathmines Township Commissioners called in Mr. Richard Hassard, to advise them as to the feasibility and cost of procuring an additional supply of water from the higher levels of the Grand Canal, and as to obtaining an independent supply from the corporation reservoirs at Stillorgan, supposing an arrangement as to price were agreed on. In sending his report, Mr. Hassard at the same time laid before the commissioners a project by which a supply of water might be obtained by gravitation from the tributaries of the River Dodder draining into the Glenesmoel Valley; and from this project the undertaking, since carried out as shown in the plan, Plate 91, does not materially differ.

Gathering Ground.—The principle of construction adopted is that known as the separation system, which has been carried out at Manchester, Halifax, and other places. The upper part of the River Dodder drainage ground, Plate 91, having an area of 4,340 acres of granitic formation, is covered with peat, as already stated, and consequently produces water more or less coloured. Immediately below this peat-covered district, there occurs an area of about 3,250 acres, mostly bare uncultivated mountain and sheep walk, free from peat, partly of granitic but principally of metamorphic and silurian formation, producing water of great purity; and owing to the occurrence of some gravel beds on the hill-sides, the yield of spring water is exceptionally large. It was evident therefore that if the water from the peat-covered area could be intercepted, and

passed by or through the lower district without mingling with that to be obtained from the latter, a supply of excellent water could be secured for township use. This arrangement has been carried out. The water as taken from the streams in dry weather contains about 4 grains of solid matter per gallon, and is of about 5 degrees of hardness: a more desirable water it would be difficult to procure.

Flood Channels and Catchwater Conduits.—The drainage area at its summit at Kippure Mountain, Plate 91, attains an altitude of 2,473 feet above ordnance datum, giving an average inclination from the head of the upper reservoir of about 1 in 10; and the sides of the valley are in many places of steeper slopes, rendering it necessary to construct the flood channels of unusual size and capacity, as the rainfall is large and during storms flows off the bare hill-sides very rapidly. The artificial watercourse, Figs. 2 and 4, Plates 92 and 93, for conveying the waters of the River Dodder, the Cot brook, and the Slade brook, from the peat-covered district of 4,340 acres, past the upper reservoir, is capable of carrying off 120,000 cubic feet of water per minute, or $27\frac{1}{2}$ cubic feet per minute per acre of drainage; and as shown at WW, Plate 92, the overflow weirs of the reservoirs are each 200 feet in length. The weirs and by-wash at the upper reservoir are shown in Plates 95 and 96. The streams and springs on the western side of the valley, adjacent to the upper reservoir, are conducted into it by culverts passing underneath the artificial watercourse; the construction of these culverts is shown in Plates 93 and 94. In the lower part of the valley the waters from the Ballinascorney and Ballymaice streams, distant respectively $1\frac{1}{4}$ and 2 miles, are intercepted, the direction of their currents reversed, and the water conducted back into the upper reservoir by catchwater conduits constructed along the hill-sides, Plate 91, and Fig. 3, Plate 92. The Piperstown stream on the eastern side of the valley is carried across it by a syphon pipe 2 feet diameter, passing through the lower reservoir and delivering into the catchwater conduit on the western side, Fig. 3, Plate 92.

Reservoirs.—There are two reservoirs, Plates 91 and 92; the upper impounds the pure water chiefly for township supply, and the lower receives the peaty water for mill-owners' use only. It was at first intended to construct a reservoir of large storage capacity in the lower part of the valley, for impounding the water from the peat-covered district, and from this reservoir to give out not only the amount of compensation water due to the lower district of 3,250 acres, but in addition a largely increased supply for mill-owners' use, for which it was proposed to tax them per foot of occupied fall, as has been done in other places. The mill-owners objecting to this, it was arranged during the progress of the bill through parliament that the water from the upper district should be diverted past both reservoirs, excepting at such times as the volume of the stream flowing from it exceeded 1,500 cubic feet per minute, which is as much as the mills can use; and that the commissioners should have power to impound all water in excess of this flow. With this object, works and gauges have been provided which ensure that 1,500 cubic feet per minute must pass down for mill-owners' use before any water from the upper district can flow into the reservoirs; and from the weir E, Plate 92, immediately above the lower reservoir, the 1,500 cubic feet per minute secured preferentially to the mill-owners is conveyed partly by an open conduit, and partly by a line of iron pipes 27 inches diameter, laid through the lower reservoir and terminating in the old course of the river below the reservoir embankment. Consequent on this arrangement the lower reservoir has been constructed of much less extent and capacity than originally intended.

Embankments.—There is nothing very unusual in the construction of the works, the two embankments being formed in the ordinary way, with slopes of 3 to 1 on the inner and 2 to 1 on the outer faces, Plates 92 and 102. At both however there occurred on the eastern side of the valley veins and deposits of sand and gravel, extending for a considerable distance into the hill, and rendering it necessary to follow them in by headings driven one over another and filled with concrete, the ground being too steep for open trenches. This

operation was one of considerable difficulty, owing to the loose nature of the sand and the quantity of spring water met with. The lower heading at the upper embankment was extended 120 feet into the hill-side, until the deposit of sand had been completely cut through and a wall of hard blue clay reached. Into this clay the heading was carried sufficiently far to ensure a sound junction being effected between the concrete filling and the impervious material at its termination. From the floor of the lower heading a trench was then sunk to a depth of 32 feet, when the hard clay was reached; and the whole was refilled with carefully rammed concrete. After this the next heading was proceeded with, and filled up with concrete in the same manner; and so on until a height of 84 feet from the bottom was attained, when the work was completed by a short length of open trench. The headings being only 5 feet in height and all heavily timbered, this part of the work was necessarily very slow and tedious, greatly retarding the progress of the upper reservoir embankment, and consequently the final completion of the works. The upper reservoir, Fig. 2, has an area of 57 acres and contains 357,000,000 gallons, its embankment being 70 feet in height at the deepest part, Fig. 34. The lower, Fig. 3, has an area of 30½ acres and contains 160,000,000 gallons, its embankment having an extreme height of 55 feet, Fig. 35.

Eduction Tunnels and Valve Towers.—Plates 100 to 103. The eduction tunnels, through which the River Dodder was diverted during the progress of the embankments, are constructed in the solid ground on the western side of the valley, and entirely below the puddle trenches. They are in each case 11 feet in diameter, having a sectional area of 100 square feet, Fig. 30, Plate 101; and with the exception of the central plugging, which is of brickwork, Fig. 34, are built entirely of rubble masonry backed with concrete. The outlet towers are placed at TT, Plate 92, in close proximity to the forebays of the tunnels, and are reached by footbridges from the embankments, Plates 102 and 103. As shown in Plate 100, there are three openings N in the outlet tower of the upper reservoir, through which the water is drawn off at different levels for township

supply; and from the base of the tower, extending through the eduction tunnel to the valve chamber, are laid two lines of pipes, as indicated in Plate 92, one of 24 inches diameter for emptying purposes A, and the other D of 16 inches diameter for the supply of the township, Plate 100. A second emptying pipe 18 inches in diameter is inserted in the plugging of the eduction tunnel, and discharges into the lower reservoir below the weir E at the mill-owners' slot-gauge, Plate 92. The 24-inch and 16-inch pipes are controlled, in addition to the ordinary valves, by stop plug-valves suspended from a crab winch H, Fig. 28, Plate 100, and guided on to their seats by a specially designed arrangement in the form of a large bell-mouth attached to the upturned base below, Plate 104. From the outlet tower of the lower reservoir are laid two lines of pipes, of 27 and 24 inches diameter: the larger F forms a junction with the line of 27-inch pipes L laid through the reservoir, which conveys the water from the upper district; and the smaller M, for emptying purposes, also extends through the eduction tunnel and valve chamber to the mill-owners' gauge-basin S below, Fig. 3, Plate 92.

Masonry.—All the masonry in the storm channels, overflow weirs, eduction tunnels, valve towers, bridges, sheeting of the embankments, and works generally, is of common rubble stone found in the locality, built with Portland cement mortar in the proportion of one part of cement to three parts of sharp sand; and the concrete, of which a large quantity has been used, is composed of excellent gravel, brought down by floods and found in the valley, in the proportion of one part of cement to six parts of gravel. No lime has been used in any part of the works.

Floods.—The heaviest floods experienced during the construction of the works occurred on 1st September 1883 and on 16th October 1886. On the first occasion there fell on the site of the reservoirs 3·80 inches, and on the second 3·68 inches of rain, the duration of the storm in each case being about nineteen hours. No means of accurately measuring the volume of the first flood existed at the

time of its occurrence; but the second was carefully gauged, and at its height amounted to 20 cubic feet per minute from each acre draining to the point where the measurement was taken.

Township Supply.—For township use the water can be drawn off from the upper reservoir at three different levels, as already stated, and as shown in Plate 100; and after passing through a gauge basin B, Plate 92, is conveyed by a line of 15-inch pipes $4\frac{1}{2}$ miles in length, with two intermediate relief pits PP on its course, Plate 91, to a service reservoir at Ballyboden, distant about $2\frac{3}{4}$ miles from the township, at an altitude of 325 feet above ordnance datum, and 175 feet above the highest part of the township at Terenure. From this reservoir, after passing through copper wire-gauze screens, the water is conveyed to the township by a line of 18-inch pipes laid in the public roads, Plate 91.

Compensation Water and Preferential Supply to Mill-owners.—The water for mill-owners' compensation is drawn off from the lower reservoir, and after passing through a gauge basin S, Fig. 3, Plate 92, is delivered into the old course of the river immediately below it. The preferential supply of 1,500 cubic feet per minute from the upper district is diverted past the lower reservoir by a weir E placed across the old river bed, and is then passed through a slot-gauge G which is capable of delivering the stipulated quantity with a mean head of 9 inches, this being the height of the crest of the adjoining weir, as shown in Plates 98 and 99; a transverse section of the slot-gauge to a larger scale is shown in Fig. 26. From the slot-gauge the water flows down an open conduit about 100 yards long to the line of pipes of 27 inches diameter, by which it is conveyed through and past the lower reservoir into the old river course, according to the requirements of the act of parliament. At the head of the 27-inch pipe is placed a sluice C, Plate 92, with a weir adjoining, arranged as shown in Fig. 19, Plate 96, and in Plate 97; the object of placing the sluice in this position is so to regulate the flow that only the stipulated quantity of 1,500 cubic feet per minute passing through the slot-gauge under the head of 9 inches

shall be admitted into the 27-inch pipe; the surplus in time of flood, when with an increased head the gauge passes down more than the required quantity of water, is discharged over the weir at the head of the 27-inch pipe, and so into the lower reservoir.

Total Supply of Water available.—The works are designed to secure a supply of 3,000,000 gallons daily for township use, and 2,100,000 daily for mill-owners' compensation. From the register of rainfall on the site of the works it has been ascertained that, at the termination of the unprecedented drought of 1887, which extended from 23rd May to 31st October, a period of 161 days, there would have been in stock more than fifty days' supply for both township and mill-owners' use.

General.—The works were designed and carried out by Mr. Hassard in conjunction with the author; and the resident engineers were in the first instance Mr. Henry Crook, and subsequently Mr. F. P. Dixon. The contract was let to Messrs. Falkiner and Stanford of Dublin, who were represented on the works by Mr. E. J. Jackson.

Discussion.

Mr. Edward B. Marten, Member of Council, had had the pleasure of seeing these works in the excursion there at the recent Dublin Meeting, and was very much interested with the way in which the difficulties that had presented themselves had been overcome. To the Members in general he thought complete descriptions of works of this kind were very useful, especially to those who were stationed away, and could seldom attend the meetings. The problem to be solved in the present instance was

a rather difficult one. It was necessary to convey a large quantity of water, that was not fit to be used for the township, past the very area from which the pure water for township use was to be gathered. The next problem was to increase as much as possible the area for gathering good water; and this had been done very ingeniously, not perhaps in a new way, but by so contriving the interception of streams of good water as to get the largest possible area of gathering ground for water fit for the supply of the town. There were a great many special points about the works which were interesting, and to most of which attention had been drawn in the paper; but perhaps the only one that he had not been able quite to understand at the time of visiting the reservoirs was in connection with the weirs. It was intelligible enough that the water not wanted was passed over very long weirs; but he did not quite understand why there should be a weir to raise the water in the artificial diverted channel at all; and another point was, why that weir should be cut with holes or slots through it just below its crest, as shown in Figs. 13, 14, and 18, Plates 95 and 96. It was a construction that looked as if it was done for some particular purpose, and as if the water would go through the holes to a certain extent, and then if it rose higher would have to pass over the crest of the weir. He did not quite see the object of that twofold provision.

Mr. John G. Mair asked what was the extent of the population that was being supplied from these works. The author and Mr. Hassard he thought were to be congratulated upon such a result as was mentioned in the paper, namely that after a period of 161 days' drought there would have remained in stock in the reservoir fifty days' supply for both township and mill-owners' use. A great deal had been heard about the scanty supply in the drought of 1887; and he thought that when waterworks were constructed, in which after a drought of more than five months there was a fifty days' supply, not only for the township but also for the mill-owners, the result was one for great congratulation for the people who lived in the district, and reflected the greatest credit on the engineers. The

(Mr. John G. Mair.)

way in which the water was taken out of the reservoirs and passed through the embankments was described as being by pipes with plug valves at their inner ends, the pipes themselves passing through the reservoir banks while the valves were in the outlet towers in the reservoirs. That was a much more satisfactory way of taking the water out of a reservoir, he thought, than by putting a valve in the centre of the tunnel, as was done in a large number of reservoirs in the north of England; because in the latter case, if anything should go wrong with the valve, it could not be got at. The arrangements described in the paper were simple and efficient, and the outlet valves could always be got at in the event of their going wrong. The water from the upper or peat-covered area he understood was intercepted and taken by a separate channel for the mill-owners' use, so as to prevent it from mixing with the better water collected from the lower area for the town supply; and he regretted he had not been at the Dublin Meeting, when he should have been glad to see how this was accomplished. The quantity of rain that had fallen on the site of the reservoirs in the two floods mentioned in the paper appeared to be very exceptional, even for Dublin where there was so considerable a rainfall; and he should be glad to learn whether such an excessive quantity of rain was known anywhere in England.

Mr. Tyrrell replied that the water flowing from the upper or peat-covered area of 4,340 acres, which was entirely unsuitable for the township supply, had been diverted past the upper reservoir by means of an artificial channel, and was discharged into the lower reservoir below the upper embankment. That channel would have to deal with floods of considerable magnitude, and it had been designed to carry off floods of 120,000 cubic feet per minute, equal to 27½ cubic feet per acre of drainage per minute, or at the rate of about 11 inches of rain in 24 hours. In the case of any obstruction to the channel, owing to land slips or other unforeseen circumstances, the works adjoining both the upper and lower embankments, such as overflow weirs, tumbling bays, by-washes, and so on, had been designed of sufficient discharging capacity to carry off 30 cubic feet

per acre per minute, or a rainfall of 12 inches in 24 hours. During the construction of the two reservoir embankments, two large culverts, one passing under each bank, were formed for the purpose of carrying off the flow of water in the river. Although the ordinary summer flow of the river could all be discharged through a 16-inch pipe, it was deemed necessary to construct these culverts 11 feet in diameter; and still they were not large enough to carry off the floods which had actually occurred. The two tunnels were each capable of discharging 65,000 cubic feet with a velocity of 650 feet per minute, equal to 15 cubic feet per minute per acre of drainage, and to 6 inches rainfall in 24 hours. With tunnels of that size, having an area of 100 square feet and a discharging capacity of 65,000 cubic feet per minute, it was thought that all reasonable precautions had been taken. On the occasion of the great flood on 1st September 1883, when there fell on the site of the reservoirs nearly four inches of rain, the rainfall commenced about eleven o'clock in the morning. There was a heavy downpour during the afternoon, and about six o'clock in the evening the water in the upper tunnel was running 3 feet deep. An hour later, at seven o'clock, the upper tunnel was running completely full, and the water in the forebay was 2 feet above the soffit of the arch at that point. The embankment of the upper reservoir had so far progressed that the inner portion of it was $2\frac{1}{2}$ feet above the soffit of the arch; and the lower embankment was in like manner $5\frac{1}{2}$ feet above the arch of the lower tunnel. Soon after seven o'clock the water topped the upper embankment, flowed over it, and rapidly carried away a large piece, and passed down to the lower reservoir. There the embankment being three feet higher allowed a longer time for the water to accumulate, while the lower tunnel was of course discharging at the same rate as the upper. At midnight the water had reached within one foot of the summit of the lower bank, so far as it had been constructed. Then it began to subside, and for two hours it fell; gradually it rose again, and at three o'clock in the morning it topped the lower bank, and, as in the case of the upper, it carried away a large quantity of material, breaking through the bank and rushing down the river course. If the embankments had each been carried a few feet higher at the time, or

(Mr. Tyrrell.)
if shoots had been provided, the accident would not have happened; but the contractors thought that the discharging power of the tunnels of 11 feet diameter was ample for any ordinary flood, and they had neglected those precautions. On the occasion of the second flood on 16th October 1886, the embankments were considerably higher, and the tunnels were able to carry off the water, and no damage was done.

The object of placing the long weir with culverts through it (page 531) at the termination of the artificial watercourse, Figs. 13, 14, and 18, Plates 95 and 96, was in times of heavy flood to prevent the great body of water impinging on the side walls of the tumbling bay, in consequence of the direction of the current being suddenly turned at right angles, and to check the rush and swirl of water which at such times would otherwise have taken place in the diverted channel at the point of its junction with the tumbling bays and by-wash. This precautionary work had entirely answered its purpose. The twenty culverts through the weir were of sufficient discharging capacity to carry off not only the ordinary flow of the river, but even considerable floods; while at times of excessive rainfall, when the diverted channel was running nearly full, the surplus water passed quietly away over the crest of the weir, leaving comparatively still water behind it, the velocity of the water in the channel being no greater at this point than in any other part of the artificial watercourse.

The rainfall over the district was no doubt excessive (page 532). At Glenesmoel Lodge, Fig. 1, Plate 91, situated about a mile above the upper reservoir and at an altitude of 800 feet above the sea, the register of rainfall during the last five years had been as nearly as possible double that in Dublin. It was a curious circumstance that this proportion had been maintained without any appreciable fluctuation year by year, both dry and wet. For instance, during the driest year 1887 the rainfall at Glenesmoel Lodge was 35·01 inches, in Dublin 16·60. During the wettest year 1886 the rainfall at the Lodge was 64·51 inches, in Dublin 31·40. The average annual rainfall at the Lodge during the five years was 49·73 inches, in Dublin 24·93. On the occasions however of the heavy floods

mentioned in the paper, when nearly 4 inches fell on the site of the reservoirs, there was only about $1\frac{1}{2}$ inch registered in Dublin.

The capacity of the reservoirs to work through a period of protracted drought, such as that experienced during last year, had been referred to as follows by Sir John Hawkshaw, in a recent report made to the Rathmines Township Commissioners in consequence of the mill-owners having alleged that the works as carried out would seriously affect their interests :—

"The drought of last year 1887 is the most prolonged that has been recorded. It is well known to have been in respect of dryness a most exceptional year; and it may be taken as giving the lowest supply of water likely to be obtained. Tables of rainfall of the district have been furnished to me, and the following is derived from them. The dry period of 1887 began at the Glenesmoel Valley on May 23rd, at which time it may be assumed both reservoirs would have been full from previous rains; and continued until October 31st, extending therefore 161 days. During its continuance there was at the Glenesmoel Valley 10·23 inches of rain, the fall during the months of July, August, September, and October, averaging 2·41 inches per month, and on three occasions the fall being $\frac{3}{4}$ inch in 24 hours. The longest continuance of dry weather during the period was for about six weeks from the end of May through June to July 9th, during which the rainfall was only 0·39 inch.

"The two reservoirs when full contain

Upper reservoir . . .	357,000,000	Gallons.
Lower do. . . .	160,500,000	
		517,500,000
Of the 10·23 inches of rain falling during the dry period of 1887 at least 6 inches would run off the 3,000 acres into the upper reservoir, the quantity amounting to		408,375,000

To this must be added the surplus water that would flow into the lower reservoir from the upper district of 4,340 acres at such times as the volume of the stream exceeded 1,500 cubic feet per minute, or as follows :—

(Mr. Tyrrell.)

1887	Rainfall. Inch.	Available. Inch.	Surplus. Gallons.	
July 9	0·73	0·40	25,884,000	
Aug. 12	0·48	0·25	11,115,000	
„ 17	0·84	0·55	40,653,000	
„ 27	0·32	0·20	6,192,000	
Sep. 1	0·86	0·60	45,576,000	
„ 6	0·30	0·20	6,192,000	
Oct. 8	0·31	0·20	6,192,000	
„ 23	0·30	0·20	6,192,000	
„ 30	0·37	0·25	11,115,000	
				159,111,000

Total available for supply 1,084,986,000

Deduct joint supply for township and mills, that is to say

3,000,000 gallons for township daily

2,100,000 „ mills „

5,100,000 × 161 days 821,100,000

Remaining in stock in the two reservoirs on 31st October when the drought ceased 263,886,000

"This is equivalent to as much as $51\frac{3}{4}$ days' supply existing at the cessation of the prolonged drought. There is therefore no ground for the allegation of the mill-owners that the works as constructed will affect their interests injuriously. On the contrary, the construction of the works places the mill-owners in a much more satisfactory position than before; a large quantity of water would without storage go to waste in floods and be lost for commercial purposes. It will now for the most part be utilized, giving a regular and constant, instead of an irregular and variable, supply for mill and manufacturing purposes."

The present population of the township was 30,000. The works would give three million gallons per day, and at 30 gallons per head would therefore suffice for between three and four times the existing population.

The Chairman had seen it authoritatively stated that, as far as the experience of Ireland generally went, a large portion of the rain

coming from the Atlantic dropped on the Green Island to the extent of even more than 80 inches per annum at some places on the west coast, and gradually diminished eastwards to 60 and 40 inches, until the average at Dublin was 25 inches a year. Consequently, although there might be times of exceptional drought, there was no danger he thought of these reservoirs failing for the population which they were intended to supply.

The Members would no doubt join in heartily thanking Mr. Tyrrell for his paper, and for the pleasant reminder which it gave them of the visit they had so much enjoyed to the Rathmines Water Works.

RESEARCH COMMITTEE ON RIVETED JOINTS.

REPORT UPON EXPERIMENTS ON DOUBLE-RIVETED LAP AND BUTT JOINTS MADE WITH THICKER PLATES AND LARGER RIVETS CLOSED UNDER HEAVIER PRESSURES, SERIES XIV.

By Professor ALEXANDER B. W. KENNEDY, F.R.S., *Honorary Life Member.*

The Research Committee on Riveted Joints, having made thirteen series of experiments, of which the three last were reported to the Institution in April 1885, placed also before the Members on the same date an Abstract of the whole results, so far as they had gone, drawn up by the Reporter.* This Abstract was read and discussed at that meeting of the Institution. The Committee subsequently decided that it was advisable to make further experiments on Double-Riveted Lap and Butt Joints, to a small extent in duplication of the former tests, but mainly with the use of heavier hydraulic pressures in riveting, thicker plates, and larger rivets. These experiments, which constitute Series XIV of those made by the Committee, form the subject of the present Report. In one respect at any rate, namely the size of the rivets used in the larger joints, they are probably unique. Their principal results are given in the subjoined Tables XXXIX and XL, pages 566–569.

The plate used in the joints was kindly supplied, as on former occasions, by the Landore Siemens-Steel Co. The preparation and riveting up were done by Messrs. Fielding and Platt, of Gloucester, the machines used for riveting being those of Mr. Tweddell. The actual testing of the joints themselves was carried out by the Reporter on the 300-ton machine at Lloyd's Proving House at Netherton, the use of which was kindly granted on very liberal terms. The very numerous tensile tests of plate strips, etc.,

* For complete list of previous Series I to XIII see Proceedings April 1885, Table XXXVI, page 263.

and the shearing tests, were made in the Engineering Laboratory at University College, London.

Series XIV consist of thirty-three riveted joints in all. Of these nine are in $\frac{3}{8}$-inch plate, fifteen in $\frac{3}{4}$-inch plate, and nine in 1-inch plate. The thirty-three joints are divided (see Tables XXXIX and XL, pages 566–569) into eleven sets of three each, each set receiving a different distinguishing letter. The sets marked A, B, and C were all taken from one plate; D, E, and H from another; F and G from a third; and K, L, and M from a fourth plate. In all cases the metal was cut so that the direction of pull in the joint was in the direction of the length of the plate. Detailed drawings of the joints are given in Plates 105 to 109, and the dimensions marked thereon need not be here recapitulated; the drawings also give details of the dimensions of the rivets used, from which it will be seen that ample length was provided to make good ends.

The results of the first eighteen experiments are given in Table XXXIX, pages 566–567. These are all on $\frac{3}{8}$ and $\frac{3}{4}$-inch plate with the diameters of rivets formerly used, but with much heavier pressures used in riveting than those formerly employed, these heavier pressures being fixed by Mr. Tweddell. For comparison's sake three lap-joints in each thickness of plate were also riveted up by hand. Out of the nine joints in each thickness of plate there are thus three (A and D) hand-riveted lap, three (B and E) machine-riveted lap, and three (C and F) machine-riveted butt. In form they differ from most of those of Series XII and XIII in that each joint contains an even number of rivets, and not an odd number. In this respect they were the same as the former $\frac{3}{4}$-inch double-riveted butt-joints (Table XXXII, Proceedings 1885, page 224, and Fig. 4, Plate 27). This point was discussed in the last Report of this Committee (Proceedings 1885, page 213), and will be further referred to. It was thought at the time that it would be better to make this alteration in future experiments, but the result leaves it doubtful whether or not the change was advisable.

In Table XL, pages 568–569, are given the results of experiments on double-riveted lap and butt joints in $\frac{3}{4}$ and 1-inch plate, with extra large rivets, and with specially heavy riveting pressures, fixed

by Mr. Tweddell. All these joints are of course machine-riveted. In the $\frac{3}{4}$-inch lap-joints (G) the rivets were 1·6 inch diameter; in the 1-inch lap-joints rivets of 1·3 inch diameter were used in three joints (K), and rivets of 1·75 inch diameter in three joints (L). The $\frac{3}{4}$-inch butt-joints (H) were made with 1·6 inch rivets, and the 1-inch butt-joints (M) with 1·3 inch rivets.

The experiments will probably be most easily followed if taken up in order, comparing each set with the one which it most resembles of those formerly tested. For this purpose we may begin with the joints A and B in Table XXXIX, pages 566–567, double-riveted lap-joints in $\frac{3}{8}$-inch plate, comparing them with those of Table XXIX (Proceedings 1885, pages 201 and 218. Compare also Fig. 1, Plate 105, with Fig. 1, Plate 27, of 1885.) Here, although it was intended that the plates should be precisely of the quality formerly used, it was unfortunately found out only too late that the plates sent for Series XIV had a tenacity of only about 25 to 26 tons per square inch, instead of 29 to 30 tons. Besides being deficient in tenacity, the plate was distinctly laminated in appearance, and was wanting in ductility, as is shown in the tests in Table XXXVII, pages 550–551, where the results of tensile tests on three pieces cut from each joint are given. In the hand-riveted joints slip became visible at 32·5 per cent. of the breaking load, in the machine-riveted at 43·2 per cent., as against 25·2 per cent. and 50 per cent. formerly. The pressure used in riveting these first joints was fixed by Mr. Tweddell at 35 tons,* or nearly the same as before, although he was disposed at first to think this pressure somewhat too high for the small rivets. There was no other sensible difference between the results of the hand and the machine riveting, except that

* An accumulator having 6 inches diameter and 10 feet stroke was used in all cases, and was connected to the machine by small pipes, which did away with any sudden drop. The distance the ram lowered in closing a rivet was as follows:—

Pressure 100 tons,	...	drop 31 inches.
„ 70 „	...	„ 23 „
„ 35 „	...	„ 10 „

the latter gave slightly the higher efficiency. The efficiency of the joints was 74 per cent., against 80 per cent. formerly reached in the joints which gave way in the plate. This reduced value is owing entirely to the absence of any considerable excess of strength in the plate due to perforation. In the former joints this excess amounted to 10·5 per cent. (given as "exactly 10 per cent." in 1885, page 203); here it was only 2·7 per cent. All the joints gave way in the plate, the shearing stress in the rivets reaching about 21 tons per square inch. Table XXXVIII, page 560, shows that the average shearing resistance of the rivet steel was 24·6 tons per square inch. It must be noted however that one set of the former joints (Series XIII, Table XXIX) gave way by shearing the rivets at about 21·5 tons per square inch, reaching only 67 per cent. efficiency. If these joints be taken into account, the mean efficiency of the seven former joints is 76·4 per cent., against 74·0 in the present ones; but this is probably not so satisfactory a method of comparison as the other.

The double-riveted butt-joints in $\frac{3}{8}$-inch plate (C in Table XXXIX, pages 566–567) compare with the joints of Series XII and XIII in Table XXX. The dimensions are the same, with the exception of the breadth and number of rivets; the pressure used in riveting was 35 tons, or practically the same as before, the rivets being 0·7 inch diameter in both cases. Slip became visible only at 71·5 per cent. of the final load, as against 66·8 per cent. formerly. Fracture occurred in the plates in all cases, the stress in the rivets being inevitably very small in this type of joint unless the bearing pressure be excessive, and this was kept under 40 tons per square inch. The efficiency of the joints was 75 per cent., as against 79·2 per cent. formerly reached, this difference being again due to the very small excess of strength consequent upon perforation, which was only 1 per cent. against 6 per cent. formerly.

Going on now to the $\frac{3}{4}$-inch plates (which Table XXXVII, pages 552–555, shows to have been of much more satisfactory quality than the thinner plates), we can compare first the sets D and E of Table XXXIX, pages 566–567, with the joints given

in Table XXXI. These are all double-riveted lap-joints, and the old and new sets are identical except for the differences formerly specified, and for the pressure used in riveting, which was 70 tons* in Series XIV against 35 tons in Series XII and XIII, the rivets being 1·1 inch diameter in all cases. In the hand-riveted joints slip began at 29·8 per cent. of the maximum load, as against 21·2 per cent. formerly, while the joints riveted under heavy pressure show no corresponding gain, slip beginning now at 31·8 per cent. against 33·7 per cent. before, or practically at the same point. The rivet bar used in these joints had a shearing resistance of 24 to 26 tons per square inch, while rivets made from that bar had a resistance below 20 tons per square inch; the particulars are given in Table XXXVIII, page 561. Three out of the six joints tested broke in the rivets, the average shearing stress being 17·9 tons per square inch. (In these joints the rivets were of course only in single shear, and exposed to some tension owing to the bending of the plates; while all the shear experiments were on double shear, where no bending could occur.) In four of the earlier experiments with this type of joint fracture also occurred in the rivets, but at a much higher load, namely 21·0 tons per square inch, the mean efficiency of those joints being 61·8 per cent. The mean efficiency of the three joints of Series XIV which sheared the rivets was only 52·4 per cent., on account of the much smaller resistance of the rivets. In the former experiments five joints broke in the plate, with a mean efficiency of 70·2 per cent., the plate having an excess strength of 7·8 per cent. In the present series three joints broke in the plate with 65·2 per cent. efficiency, the excess strength being only 1·4 per cent.

The double-riveted butt-joints in $\frac{3}{4}$-inch plate, set F in Series XIV, compare with those of Series XII and XIII in Table XXXII, but were riveted up with 70 tons pressure instead of 35 tons. In both cases fracture occurred in the plate. Slip began at 31 per cent. of the maximum load in the earlier experiments, but this proportion is increased to 49 per cent. in Series XIV. The efficiency of the

* The riveting of Series E and F was done in a plate-closing machine, 30 tons coming on the plate first, then 40 tons on the rivet, and finally the whole 70 tons on the rivet.

joints is practically the same in both sets of experiments, being about 67 per cent. In both sets of experiments the plate showed defect instead of excess of strength; this amounted to 9·5 per cent. in Series XII and XIII, and 10·5 per cent. in Series XIV. The same type of joint however had reached 71·3 per cent. efficiency when hand-riveted in Series XI (Table XXXII), the defect of strength in that case being only 4·8 per cent.

In Table XL, pages 568–569, are given results of experiments on fifteen joints, in five sets of three each, in which larger rivets as well as higher pressures have been used. The double-riveted lap-joints in $\frac{3}{4}$-inch plate, set G, can be compared with those in Table XXXI, as well as with sets D and E of Table XXXIX, the particulars of which have just been given. These new joints G had rivets 1·6 inch diameter, and were riveted up with a pressure of 100 tons. They were of exactly uniform strength in plates and in rivets, for the weakest broke at 240·4 tons by shearing the rivets, and the strongest at 242·4 tons by tearing the plate; the mean efficiency of the three was 69·4 per cent., as against 65·2 per cent. with the smaller rivets, being a gain of 6·4 per cent. This is in spite of the fact that there is now a loss of strength in the plate amounting to 1·8 per cent., instead of a gain of 1·4 per cent. It will be noticed also that the joints which broke in the rivets had precisely the same strength as those which broke in the plate, instead of being far weaker. The rivets sheared only at 20·1 tons per square inch, instead of 17·9 tons per square inch. It will be seen from Table XXXVIII, page 561, that the 1·1 inch rivets were much weaker in shear than the bar from which they were made (26 tons per square inch falling to 19·87); while the 1·6 inch rivets, page 563, were actually a little stronger than the bar from which they were made (23 tons per square inch against 22·85). As regards the point about which there was reason to expect the most striking improvement, it was singular to find that none occurred. Slip began at 29·2 per cent. of the maximum load, a lower percentage than before, instead of a higher one.

For double-riveted butt-joints in $\frac{3}{4}$-inch plate the set H of Series XIV, Table XL, pages 568–569, compares with set F of

Table XXXIX, and with the joints of Series XII and XIII given in Table XXXII. The new joints had 1·6 inch rivets closed under 100 tons pressure, instead of 1·1 inch rivets closed under 70 tons in set F, or under 35 tons in Series XII and XIII. All the joints broke in the plate, and showed a loss of strength of about 9 per cent., or a little less than with the same type of joint formerly. The efficiency of the joints was 67·9 per cent.; practically therefore it was unchanged. Slip became visible at 46·5 per cent. of the maximum load, a much higher percentage than in Series XII and XIII, but a little lower than for the 1·1 inch rivets in set F, in which it began at 49 per cent.

The remaining nine joints of Series XIV, Table XL, pages 568–569, were in plate 1 inch thick, so they do not compare directly with any former joints tested by the Committee, but must be considered principally by themselves. They consisted of three sets, all riveted with 100 tons closing pressure. Set K were lap-joints with 1·3 inch rivets; set L lap-joints with 1·75 inch rivets; and set M butt-joints with 1·3 inch rivets. All the joints broke by tearing the plate. The set K gave the highest plate stress at fracture of any joints in Series XIV, namely 30·9 tons per square inch, although the tensile strength of the original plates was higher in several other sets than in set K. The plate stress at fracture of the joints in set K showed an excess strength of 11·6 per cent. With this help the joints reached an efficiency of 65·4 per cent. Slip began very low, at 28 per cent. of the maximum load. The rivets stood nearly 21 tons per square inch, but did not give way. Their shearing resistance, as given in Table XXXVIII, page 562, is 23·92 tons per square inch.

In set L, although made from plate of very nearly identical quality, the excess strength practically disappeared, the joints breaking at 27·59 tons per square inch as against a plate tenacity of 27·49 tons per square inch. In spite of this, which means a loss of 11 per cent. as compared with set K, the efficiency of the joints with the large rivets rose to 66·8 per cent. The point at which slip began also rose to 34·4 per cent. of the maximum load. It

is worth mentioning that in one of the three joints of this set, L 3, *both* plates of the joint tore simultaneously at the maximum load.

The butt-joints, set M, reached a higher efficiency (69·3 per cent.) than any other of the 1 inch joints, although, as in the former cases, the plate showed defect instead of excess of strength, the defect here amounting to 6·8 per cent. Slip began at 44·3 per cent. of the maximum load. It was possible to proportion these large joints so as to get a greater stress on the rivets than in any other of the butt-joints, and here that stress reaches 18·5 tons per square inch, a stress above that at which the rivets had given way (in single shear) in sets D and E, Table XXXIX. The $1\frac{3}{4}$-inch rivet-bar and rivets both gave a shearing resistance of over 23 tons per square inch in the testing machine, Table XXXVIII, page 564.

It is obvious from the figures given above that all the differences between the strength of the joints in Series XIV and of those in Series XI to XIII lie within the limits covered by what has been called the "excess strength due to perforation." This matter has been dealt with at some length in former Reports, and especially in the "Abstract of Results" (Proceedings 1885, page 249) under clause (i) of the general conclusions. This clause may perhaps be here repeated with advantage:—"The metal between the rivet holes has a considerably greater tensile resistance per square inch than the unperforated metal. This excess tenacity amounted to more than 20 per cent., both in $\frac{3}{8}$-inch and $\frac{3}{4}$-inch plates, when the pitch of the rivets was about 1·9 diameters. In other cases $\frac{3}{8}$-inch plate gave an excess of 15 per cent. at fracture with a pitch of 2 diameters, of 10 per cent. with a pitch of 3·6 diameters, and of 6·6 per cent. with a pitch of 3·9 diameters; and $\frac{3}{4}$-inch plate gave 7·8 per cent. excess with a pitch of 2·8 diameters." As variation of this excess strength may thus account for variations in the strength of joints considerably greater than those which have occurred between the joints now under consideration, the proper interpretation of the experiments seems really to depend on the method of dealing with this point. An examination was therefore made, with special reference to this matter, of all the experiments carried out by the Committee; and it

shows that—without any exceptions save those of two small joints made with $\frac{1}{2}$-inch rivets in $\frac{3}{8}$-inch plate in Series VI—they point to the following conclusions :—

(i) The "excess strength due to perforation" is *increased* by anything which tends to make the stress in the plate uniform, and to diminish the effect of the narrow strip of metal at the edge of the specimen, and especially (*a*) by an increase in the number of rivets, and (*b*) by the use of an odd instead of an even number of rivets in a double-riveted specimen, so as to get the narrow strip symmetrically on both sides instead of only on one side of the specimen.

(ii) It is *diminished* by increase in the ratio $\frac{p}{d}$ of pitch to diameter of hole: so that in this respect it becomes less as the efficiency of the joint increases.

(iii) It is *diminished* by any increase in hardness of the plate.

(iv) For a given ratio $\frac{p}{d}$ of pitch to diameter of hole it is also apparently *diminished* as the thickness of the plate is increased. The ratio of pitch to thickness of plate does not seem to affect this matter directly, at least within the limits of the experiments.

It is sufficient here to cite one or two instances in illustration of these points. The maximum excess strength found was in Series VIII, Tables XXII, XXIV, and XXXIV, where with seven rivets in breadth and ratio $\frac{p}{d} = 1 \cdot 95$ it was 15 per cent., and with $\frac{p}{d} = 1 \cdot 91$ it was 24·8 per cent., taking into account those joints only which broke in the plate. Table XXIX gives 10·5 per cent. with $\frac{p}{d} = 3 \cdot 62$, and Table XXX 6 per cent. with $\frac{p}{d} = 3 \cdot 93$, both with $\frac{3}{8}$-inch plate. With $\frac{3}{4}$-inch plate, on the other hand, Table XXXI gives only 8 per cent. with $\frac{p}{d} = 2 \cdot 82$; and in Table XXXII, where $\frac{p}{d}$ is increased to 4·0, and where the joint is made one-sided (that is, with a whole number of pitches in breadth), the want of symmetry in the stress appears to more than counterbalance the small effect of the perforation, and in Series XII and XIII the excess is changed into a *defect* of 9·8 per cent. In Series XIV *all* the joints were made with a breadth equal to a whole number of pitches, which is the primary cause of the generally

lower value of the excess strength in this series than in former ones. The hardness of the $\frac{3}{8}$-inch plates in sets A, B, and C has no doubt further diminished the excess in these sets; and all the other experiments fall in with the general conclusions just stated. The large excess of 11·6 per cent. in set K, even with 1-inch plates, corresponds to the small value $\frac{p}{d} = 2 \cdot 42$ and the large number of rivets (eight). This excess diminishes at once to zero when $\frac{p}{d} = 3 \cdot 0$ and only four rivets are used, in set L; and further becomes a defect of 6·8 per cent. when, with the same smaller number of rivets, $\frac{p}{d}$ is increased to 3·92 in set M.

In actual practice we may consider that all the ordinary boiler joints are of sufficiently great length and have a sufficiently fair pull to entitle them to full allowance under point (i). The excess strength, as affected by ratio of pitch to diameter, may be taken as diminishing to zero when this ratio is 4·5 or more, and as being about 12 per cent. when it is 2: so that for any value of the ratio r between these numbers the percentage of excess strength may be taken as $12\left(\frac{4 \cdot 5 - r}{2 \cdot 5}\right)$ for $\frac{3}{8}$-inch plate. The experiments do not give information sufficient for enabling the thickness of the plate to be taken accurately into account; but probably 9 may be substituted for 12 per cent. in $\frac{3}{4}$-inch and 1-inch plate. If we take the figures on this basis and assume (in respect to point iii) that the plate is uniformly soft in all cases, we can bring the various experiments into comparison on a uniform basis, with the results given in Table XLI, page 570, which may probably be taken as containing the figures most nearly applicable to practice that can be deduced from the experiments so far as they have gone.

In addition to the above assumption that the plate is uniformly soft, it has been assumed in computing the results in Table XLI that all the joints are proportioned so as to break in the plate, or, if in the rivets, not until the full strength of the plate is reached; and only those joints which broke in this fashion have been taken into account in this connection. The question of the irregularity in the shearing resistance of steel, emphasised in a former report, is still further brought to the front by these experiments, Table

XXXVIII, pages 560–564, and becomes of special practical importance in view of the strong wish which has recently been expressed to raise the allowable working pressure in marine boilers.

Besides Tables XXXIX and XL, which give the result of tests of the riveted joints themselves, this Report is accompanied by two other Tables, which have been already referred to. In Table XXXVII, pages 550–559, are given the results of tensile tests of three strips cut out of the uninjured part of each of the joint plates which actually broke in the joint tests. Tests had previously been made of pieces cut from the scrap of the plates from which the joints were made; but the results of these tests were not sufficiently regular to be of much use, and the tests in Table XXXVII were therefore made. The reference numbers and letters are sufficient to identify the pieces cut from each particular joint. A summary of all these eighty-four tensile tests is given at the end of the Table, pages 558–559.

Table XXXVIII, pages 560–564, gives the results of sixty-nine shearing tests of the rivets and the rivet-steel used. All these tests were made in double shear, on test pieces of the form shown in Fig. 10, Plate 29, of the Committee's last Report (Proceedings 1885). The two "lots" of rivet bars mentioned in the Report were received by Messrs. Fielding and Platt at different times from Landore, but were supposed to be of the same quality. Both lots were used in the making of the joints. The smaller sized rivets were not tested as rivets; the bar has a fairly uniform shearing resistance of 23 to 24 tons per square inch. The 1·1 inch bar, page 561, differs a good deal in the two lots, and the rivets are very greatly weaker than the bar from which they were made. There is also a good deal of difference between the rivets made from the two lots of 1·3 inch bar, page 562, but their average agrees fairly with that of the bar; and the same is true of the larger sizes. It is clear that it is perfectly possible to make the bar into rivets without in the smallest degree reducing its shearing resistance. The rivets used in the experiments were all made by hand for Messrs. Fielding and Platt at the Gloucester Wagon Works.

The final Table XLI, page 570, has already been referred to. It contains a summarised statement of the type and leading dimensions of the joints of the four series XI to XIV, with the efficiencies worked out on the basis already discussed, so as to eliminate accidental variation, as far as possible, and to obtain figures which will be as closely as possible comparative for joints of similar materials. With joints of iron plate, or of harder steel, no doubt other figures may be obtained; but it is believed that the figures here given are not far from being the maximum likely to be obtained with double-riveted lap and butt joints made in material such as that used by the Committee. The general conclusions to be drawn from this Table appear to be that for $\frac{3}{8}$-inch plate, with ordinary diameter of rivet, the lap-joint is very nearly as strong as the butt, and an efficiency of 75 to 76 per cent. can be reached. For $\frac{3}{4}$-inch plate the butt-joint is considerably stronger than the lap, with the same size rivets; an increase of size of rivets considerably increases the efficiency of the joints. The figures are, roughly, 72 and 68 per cent. for 1·1 inch rivets, and 76 and 74 per cent. for 1·6 inch rivets. The butt-joints made with 1·1 inch rivets however, but with 70 tons closing pressure, reach an efficiency of 76 per cent.—as high as the similar joints with larger rivets. With 1-inch plate the butt-joint has an enormous advantage over the lap with the same sized rivets, and even over the much stronger lap with larger sized rivets. It will be remembered that the comparison here made is one of *strength* only, and not one of suitability for use in boilers on other grounds.

TABLE XXXVII. (*continued to page* 559)

Series XIV. *Elasticity and*

Test number, and Mark on piece.	Dimensions of Strips of 6 and 10 inches length.			Limit of Elasticity per square inch.		Breaking Load per square inch.	
	Breadth. Inch.	Thickness. Inch.	Area. Sq. Inch.	Lbs.	Tons.	Lbs.	Tons.
13037 A 1	0·967 0·967 0·966	0·406 0·406 0·411	0·392 0·392 0·397	36,750 37,360 37,120	16·41 16·68 16·57	56,260 58,320 58,130	25·12 26·04 25·95
			Means	**37,080**	**16·55**	**57,570**	**25·70**
13038 A 2	0·940 0·940 0·940	0·410 0·411 0·410	0·385 0·386 0·385	36,390 38,080 38,190	16·25 17·00 17·05	56,740 56,280 56,350	25·34 25·13 25·17
			Means	**37,550**	**16·77**	**56,460**	**25·21**
13039 A 3	0·965 0·966 0·966	0·408 0·408 0·408	0·394 0·394 0·394	37,580 37,760 38,920	16·78 16·86 17·37	57,180 57,870 58,330	25·52 25·84 26·03
			Means	**38,090**	**17·00**	**57,790**	**25·80**
13040 B 1	0·987 0·987 0·966	0·401 0·405 0·403	0·396 0·400 0·389	36,900 35,840 37,100	16·47 16·00 16·56	53,880 52,050 53,060	24·05 23·24 23·69
			Means	**36,610**	**16·34**	**53,000**	**23·66**
13041 B 2	0·988 0·988 0·988	0·405 0·408 0·405	0·400 0·403 0·400	38,980 39,520 38,230	17·40 17·64 17·07	57,120 56,930 58,090	25·50 25·42 25·94
			Means	**38,910**	**17·37**	**57,380**	**25·62**
13042 B 3	0·987 0·966 0·987	0·410 0·412 0·412	0·405 0·398 0·407	38,560 39,050 39,220	17·22 17·43 17·51	56,760 57,670 57,200	25·34 25·74 25·54
			Means	**38,940**	**17·39**	**57,210**	**25·54**

(*see continuation on opposite page*)

(*continued from opposite page*) TABLE XXXVII.

Tenacity of Steel Plates used.

Ratio of Limit to Break.	Extension in length tested.		Reduction of Area at fracture.	Calculated Work of fracture per cubic inch.	Nature of Fracture.
		Per cent.	Per cent.	Inch-Tons.	
0·653	In length of 6 inches.	18·7	43·0	4·15	Silky; slightly laminated.
0·640		25·0	48·1	5·73	Do. do.
0·639		23·3	50·1	5·71	Do. do.
0·644		**22·3**	**47·1**	**5·20**	
0·641		25·3	48·7	5·64	Slightly laminated throughout.
0·677		26·3	49·7	5·89	Do., very irregular.
0·678		25·0	47·1	5·62	Do. do.
0·665		**25·5**	**48·5**	**5·72**	
0·657	In length of 10 inches.	22·8	54·9	5·15	Silky.
0·652		21·8	54·1	4·98	Do.
0·667		22·0	50·9	5·09	Do.
0·659		**22·2**	**53·3**	**5·07**	
0·685		19·1	47·9	4·11	Silky; slightly laminated.
0·688		19·7	50·4	4·10	Do. do.
0·699		20·1	42·2	4·28	Do. do.
0·691		**19·6**	**46·8**	**4·16**	
0·682		17·2	47·8	3·92	Silky; somewhat laminated.
0·694		16·4	46·8	3·74	Do. do.
0·658		20·3	46·7	4·66	Do. do.
0·678		**18·0**	**47·1**	**4·11**	
0·679		21·6	52·7	4·89	Silky; slightly laminated.
0·677		20·8	52·4	4·77	Do. do.
0·686		18·2	44·1	4·16	Do. do.
0·681		**20·2**	**49·7**	**4·61**	

TABLE XXXVII. *(continued from preceding page)*

Series XIV. *Elasticity and*

Test number, and Mark on piece.	Dimensions of Strips of 10 and 8 inches length.			Limit of Elasticity per square inch.		Breaking Load per square inch.	
	Breadth.	Thickness.	Area.				
	Inch.	Inch.	Sq. Inch.	Lbs.	Tons.	Lbs.	Tons.
13043 C 1	0·963	0·375	0·361	41,970	18·74	62,080	27·71
	0·987	0·372	0·367	41,770	18·65	61,960	27·67
	0·989	0·372	0·368	42,150	18·82	61,800	27·59
			Means	**41,960**	**18·74**	**61,950**	**27·66**
13044 C 2	0·988	0·379	0·374	36,040	16·09	60,070	26·82
	0·988	0·379	0·374	39,260	17·53	59,440	26·54
	0·988	0·379	0·374	41,650	18·69	60,150	26·86
			Means	**38,980**	**17·41**	**59,890**	**26·74**
13045 C 3	0·985	0·408	0·402	38,800	17·32	54,780	24·46
	0·985	0·408	0·402	36,000	16·07	53,140	23·73
	0·985	0·408	0·402	38,440	17·16	56,950	25·43
			Means	**37,750**	**16·85**	**54,960**	**24·54**
13047 D 2	0·987	0·750	0·740	48,640	21·71	63,060	28·15
	0·986	0·752	0·741	38,040	16·98	63,130	28·18
	0·984	0·753	0·741	43,730	19·53	63,650	28·42
			Means	**43,470**	**19·41**	**63,280**	**28·25**
13048 D 3	0·967	0·743	0·718	41,760	18·64	60,720	27·11
	0·986	0·740	0·730	42,770	19·10	62,100	27·72
	0·968	0·745	0·721	39,110	17·46	61,250	27·34
			Means	**41,210**	**18·40**	**61,360**	**27·40**
13051 E 3	0·980	0·748	0·733	43,390	19·37	63,860	28·51
	0·985	0·750	0·739	44,270	19·77	63,360	28·29
	0·955	0·749	0·715	41,100	18·35	63,420	28·32
			Means	**42,920**	**19·16**	**63,550**	**28·37**

(see continuation on opposite page)

(continued from opposite page) TABLE XXXVII.

Tenacity of Steel Plates used.

(continued from opposite page)

Ratio of Limit to Break.	Extension in length tested. Per cent.		Reduction of Area at fracture. Per cent.	Calculated Work of fracture per cubic inch. Inch-Tons.	Nature of Fracture.
0·676	In length of 10 inches.	21·0	51·5	5·19	Silky.
0·674		17·0	48·1	4·19	Do.
0·682		17·5	50·6	4·32	Do., slight trace of lamination.
0·677		**18·5**	**50·1**	**4·57**	
0·600		14·4	48·3	3·35	Silky laminated in centre, with a few crystalline spots.
0·660		16·7	45·1	3·93	Silky, somewhat laminated.
0·692		15·5	44·1	3·73	Do. do.
0·651		**15·5**	**45·8**	**3·67**	
0·708		20·3	48·5	4·48	Silky, somewhat laminated.
0·677		19·5	50·5	4·13	Do. do.
0·675		22·0	48·1	4·99	Do. do.; drew down in two places.
0·687		**20·6**	**49·0**	**4·53**	
0·771	In length of 8 inches.	23·1	58·8	6·01	Silky.
0·603		20·5	58·5	5·01	Do.
0·687		24·4	57·5	6·21	Do.
0·687		**22·7**	**58·3**	**5·74**	
0·688		19·9	62·0	4·83	Silky.
0·689		21·5	59·4	5·34	Do.
0·639		20·8	61·0	5·00	Do.
0·672		**20·7**	**60·8**	**5·06**	
0·680		21·9	57·2	5·57	Silky, very faint lamination.
0·699		21·9	56·0	5·57	Do. do.
0·648		22·1	56·9	5·52	Do. do.
0·676		**22·0**	**56·7**	**5·55**	

TABLE XXXVII. (*continued from preceding page*)

SERIES XIV. *Elasticity and*

Test number, and Mark on piece.	Dimensions of Strips of 8 and 10 inches length.			Limit of Elasticity per square inch.		Breaking Load per square inch.	
	Breadth.	Thickness.	Area.				
	Inch.	Inch.	Sq. Inch.	Lbs.	Tons.	Lbs.	Tons.
13052 F 1	0·991	0·738	0·731	49,230	21·98	64,650	28·86
	0·991	0·734	0·727	46,200	20·63	64,260	28·69
	0·989	0·735	0·727	44,580	19·90	64,140	28·64
			Means	**46,670**	**20·84**	**64,350**	**28·73**
13053 F 2	1·000	0·740	0·740	43,710	19·52	65,680	29·32
	0·945	0·748	0·707	49,670	22·17	64,960	29·00
	0·945	0·749	0·708	49,180	21·96	64,610	28·84
			Means	**47,520**	**21·22**	**65,080**	**29·05**
13054 F 3	0·940	0·745	0·700	48,010	21·44	63,510	28·36
	0·940	0·745	0·700	47,140	21·05	64,280	28·70
	0·940	0·745	0·700	46,270	20·66	63,250	28·24
			Means	**47,140**	**21·05**	**63,680**	**28·43**
13057 G 3	0·970	0·717	0·695	53,930	24·08	64,720	28·89
	0·975	0·723	0·705	49,390	22·05	64,540	28·81
	0·975	0·722	0·704	50,290	22·45	63,930	28·55
			Means	**51,200**	**22·86**	**64,400**	**28·75**
13058 H 1	1·000	0·748	0·748	45,730	20·42	62,730	28·01
	1·000	0·748	0·748	44,120	19·70	62,170	27·75
	1·000	0·750	0·750	49,360	22·04	64,330	28·72
			Means	**46,400**	**20·72**	**63,080**	**28·16**
13059 H 2	0·985	0·750	0·739	49,550	22·12	65,210	29·12
	0·983	0·747	0·734	46,580	20·80	64,560	28·82
	0·979	0·747	0·731	45,960	20·52	64,920	28·98
			Means	**47,360**	**21·15**	**64,900**	**28·97**
13060 H 3	0·990	0·746	0·739	49,560	22·13	65,320	29·16
	0·990	0·746	0·739	47,530	21·22	64,270	28·69
	0·988	0·746	0·737	46,410	20·72	64,160	28·65
			Means	**47,830**	**21·36**	**64,580**	**28·83**

(*see continuation on opposite page*)

(*continued from opposite page*) TABLE XXXVII.

Tenacity of Steel Plates used.

Ratio of Limit to Break.		Extension in length tested. Per cent.	Reduction of Area at fracture. Per cent.	Calculated Work of fracture per cubic inch. Inch-Tons.	Nature of Fracture.
0·762	In length of 8 inches.	20·4	56·7	5·42	Silky.
0·719		21·5	55·4	5·59	Do.
0·695		23·0	56·2	5·91	Do.
0·725		**21·6**	**56·1**	**5·64**	
0·666		22·1	58·5	6·03	Silky.
0·765		23·8	59·9	6·36	Do.
0·762		23·0	59·7	6·11	Do.
0·731		**23·0**	**59·4**	**6·17**	
0·756		21·1	59·0	5·50	Silky.
0·733		21·8	61·1	5·70	Do.
0·732		21·9	58·6	5·63	Do.
0·740		**21·6**	**59·6**	**5·61**	
0·834	In length of 10 inches.	19·5	55·2	5·32	Silky.
0·765		18·9	55·8	5·02	Do.
0·786		18·2	55·9	4·83	Do.
0·795		**18·9**	**55·6**	**5·06**	
0·729		17·3	58·6	4·51	Silky.
0·710		20·2	60·3	5·06	Do; a few hard spots.
0·768		14·6	56·9	3·87	Do. do.; a roll flaw on surface.
0·736		**17·4**	**58·6**	**4·48**	
0·760		20·8	55·7	5·57	Silky.
0·722		20·2	57·2	5·28	Do.; a few hard spots; very slight lamination.
0·708		20·1	58·3	5·26	Do. do.; somewhat irregular.
0·730		**20·4**	**57·1**	**5·37**	
0·759		19·5	56·8	5·23	Silky.
0·740		20·5	55·1	5·37	Do.; a few hard spots.
0·723		19·3	59·1	5·02	Do. do.
0·741		**19·8**	**57·0**	**5·21**	

TABLE XXXVII. *(continued from preceding page)*

Series XIV. *Elasticity and*

Test number, and Mark on piece.	Dimensions of Strips of 10 inches length.			Limit of Elasticity per square inch.		Breaking Load per square inch.	
	Breadth.	Thickness.	Area.				
	Inch.	Inch.	Sq. Inch.	Lbs.	Tons.	Lbs.	Tons.
13061 K 1	1·003	0·987	0·990	44,550	19·88	62,230	27·78
	0·977	0·988	0·985	42,640	19·03	62,170	27·75
	1·005	0·985	0·990	44,560	19·89	62,230	27·78
			Means	43,920	19·60	62,210	27·77
13062 K 2	0·986	0·969	0·955	40,300	18·00	62,280	27·80
	0·990	0·969	0·959	39,410	17·60	62,620	27·96
	0·989	0·969	0·958	40,170	17·94	62,530	27·92
			Means	39,960	17·85	62,480	27·89
13063 K 3	0·996	0·990	0·986	44,030	19·66	61,220	27·33
	0·993	0·988	0·981	39,250	17·52	61,520	27·46
	1·003	0·988	0·991	39,560	17·66	61,040	27·25
			Means	40,950	18·28	61,260	27·35
13064 L 1	0·936	1·004	0·940	42,460	18·96	59,080	26·38
	0·936	1·004	0·940	44,700	19·96	60,340	26·94
	1·000	1·004	1·004	39,040	17·43	59,480	26·55
			Means	42,070	18·78	59,630	26·62
13065 L 2	1·009	0·960	0·969	44,090	19·69	62,460	27·88
	1·016	0·963	0·978	46,510	20·76	62,960	28·11
	1·013	0·960	0·973	45,000	20·09	62,990	28·12
			Means	45,200	20·18	62,800	28·04
13066 L 3	1·005	1·004	1·009	43,710	19·52	62,100	27·72
	0·983	1·001	0·984	45,190	20·17	62,620	27·96
	1·003	1·004	1·007	43,090	19·24	62,220	27·78
			Means	44,000	19·64	62,310	27·82

(see continuation on opposite page)

(*continued from opposite page*) TABLE XXXVII.

Tenacity of Steel Plates used.

(*continued from opposite page*)

Ratio of Limit to Break.	Extension in length of 10 inches. Per cent. In length of 10 inches.	Reduction of Area at fracture. Per cent.	Calculated Work of fracture per cubic inch. Inch-Tons.	Nature of Fracture.
0·716	18·7	58·5	4·70	Silky.
0·686	21·5	59·6	5·34	Do.
0·716	24·0	59·1	6·03	Do.; a few hard spots.
0·706	**21·4**	**59·1**	**5·36**	
0·648	19·2	59·8	4·71	Silky; a few hard spots.
0·630	20·9	60·1	5·12	Do. do.
0·643	20·0	59·6	4·92	Silky.
0·640	**20·0**	**59·8**	**4·92**	
0·719	20·0	59·1	4·98	Silky.
0·638	23·7	58·9	5·72	Do.
0·648	23·7	58·3	5·70	Do.
0·668	**22·5**	**58·8**	**5·47**	
0·719	20·1	59·8	4·80	Silky.
0·741	21·0	57·8	5·17	Silky; a few hard spots.
0·657	20·4	59·5	4·80	Do. do.
0·706	**20·5**	**59·0**	**4·92**	
0·706	18·4	58·6	4·63	Silky. [hard spots.
0·739	19·9	55·1	5·11	Silky, somewhat irregular, a few
0·715	20·1	57·2	5·11	Silky, with slight lamination.
0·720	**19·5**	**57·0**	**4·95**	
0·704	21·1	57·5	5·27	Silky, with slight lamination.
0·721	21·2	58·2	5·38	Silky, very slight lamination.
0·693	20·4	56·5	5·09	Do. do.
0·706	**20·9**	**57·4**	**5·25**	

TABLE XXXVII. *(continued from preceding page)*

Series XIV. *Elasticity and*

Test number, and Mark on piece.	Dimensions of Strips of 10 inches length. Breadth. Inch.	Thickness. Inch.	Area. Sq. Inch.	Limit of Elasticity per square inch. Lbs.	Tons.	Breaking Load per square inch. Lbs.	Tons.
13067 M 1	1·000	0·988	0·988	44,650	19·94	62,010	27·68
	0·988	0·988	0·972	41,600	18·57	62,540	27·92
	1·000	0·988	0·988	45,350	20·25	63,570	28·39
			Means	**43,870**	**19·59**	**62,710**	**28·00**
13068 M 2	0·994	0·993	0·987	46,110	20·59	63,410	28·31
	0·994	0·987	0·981	43,530	19·44	63,670	28·43
	0·994	0·988	0·982	44,920	20·05	63,810	28·49
			Means	**44,850**	**20·03**	**63,630**	**28·41**
13069 M 3	0·965	0·985	0·950	42,720	19·07	63,490	28·35
	0·963	0·985	0·948	44,290	19·77	63,490	28·35
	0·964	0·985	0·949	41,290	18·43	62,972	28·12
			Means	**42,770**	**19·09**	**63,320**	**28·27**
				GENERAL AVERAGES.			
			13037–39 A	**37,570**	**16·77**	**57,270**	**25·57**
			13040–42 B	**38,150**	**17·03**	**55,860**	**24·94**
			13043–45 C	**39,560**	**17·67**	**58,930**	**26·31**
			13047–48 D	**42,340**	**18·90**	**62,320**	**27·82**
			13051 E	**42,920**	**19·16**	**63,550**	**28·37**
			13052–54 F	**47,110**	**21·04**	**64,370**	**28·74**
			13057 G	**51,200**	**22·86**	**64,400**	**28·75**
			13058–60 H	**47,200**	**21·08**	**64,190**	**28·65**
			13061–63 K	**41,610**	**18·58**	**61,980**	**27·67**
			13064–66 L	**43,760**	**19·53**	**61,580**	**27·49**
			13067–69 M	**43,830**	**19·57**	**63,220**	**28·23**

(see continuation on opposite page)

(concluded from page 550) TABLE XXXVII.

Tenacity of Steel Plates used.

(continued from opposite page)

Ratio of Limit to Break.	Extension in length tested. Per cent.		Reduction of Area at fracture. Per cent.	Calculated Work of fracture per cubic inch. Inch-Tons.	Nature of Fracture.
0·720	In length of 10 inches.	18·9	59·9	4·74	Silky.
0·665		20·2	59·0	5·01	Do.
0·714		17·0	52·4	4·37	Do.
0·700		**18·7**	**57·1**	**4·71**	
0·727		18·7	49·7	4·81	Silky; a hard spot in centre.
0·684		20·5	58·3	5·21	Silky.
0·704		16·4	55·2	4·21	Do.; a few minute crystalline spots.
0·705		**18·5**	**54·4**	**4·74**	
0·673		18·3	60·0	4·62	Silky.
0·698		15·0	58·1	3·82	Do.
0·656		19·0	59·6	4·73	Do.
0·676		**17·4**	**59·2**	**4·39**	

GENERAL AVERAGES.

0·656	**23·3**	**49·6**	**5·33**	13037–39 A
0·683	**19·3**	**47·9**	**4·29**	13040–42 B
0·672	**18·2**	**48·3**	**4·26**	13043–45 C
0·679	**21·7**	**59·5**	**5·40**	13047–48 D
0·676	**22·0**	**56·7**	**5·55**	13051 E
0·732	**22·1**	**58·4**	**5·81**	13052–54 F
0·795	**18·9**	**55·6**	**5·06**	13057 G
0·736	**19·2**	**57·6**	**5·02**	13058–60 H
0·671	**21·3**	**59·2**	**5·25**	13061–63 K
0·711	**20·3**	**57·8**	**5·04**	13064–66 L
0·694	**18·2**	**56·9**	**4·61**	13067–69 M

TABLE XXXVIII. (*continued to page* 564)

Series XIV. *Shearing Resistance of Steel Rivet-Bars.*

Lot.	Test number.	Diameter sheared. Inch.	Double Sectional Area. Sq. Inch.	Shearing Load per square inch. Lbs.	Shearing Load per square inch. Tons.	Nature of Fracture.
First Lot of 0·8 inch Bar.	9051–1	0·560	0·4926	57,730	25·77	
	9051–2	0·561	0·4944	56,430	25·19	
	9051–3	0·561	0·4944	56,180	25·08	
	9051–4	0·561	0·4944	55,880	24·95	
			Means	**56,555**	**25·25**	
Second lot of 0·8 inch Bar.	10688–3	0·505	0·4006	53,700	23·98	One end silky; other crystalline-granular.
	10688–4	0·505	0·4006	54,000	24·11	Silky and crystalline-granular.
	10688–5	0·503	0·3975	54,420	24·29	Silky.
	10688–6	0·503	0·3975	53,810	24·02	One end silky; other silky and crystalline-granular.
			Means	**53,982**	**24·10**	
Averages of two lots of 0·8 *inch Bar*				**55,268**	**23·17**	*Averages of two lots.*
First lot of 0·7 inch Bar.	9052–1	0·561	0·4944	56,240	25·11	
	9052–2	0·560	0·4926	56,270	25·12	
	9052–3	0·561	0·4944	55,700	24·87	
	9052–4	0·563	0·4980	55,120	24·61	
			Means	**55,832**	**24·92**	
Second lot of 0·7 inch Bar.	10689–3	0·504	0·3991	52,090	23·26	One end silky; other silky and crystalline-granular at centre.
	10689–4	0·504	0·3991	53,440	23·86	
	10689–5	0·502	0·3958	52,910	23·62	Silky.
	10689–6	0·502	0·3958	51,690	23·08	Silky; crystalline-granular in centre.
			Means	**52,532**	**23·45**	
Averages of two lots of 0·7 *inch Bar*				**54,182**	**24·18**	*Averages of two lots.*

TABLE XXXVIII. *(continued from preceding page)*

Series XIV. *Shearing Resistance of Steel Rivet-Bars and Rivets.*

Lot.	Test number.	Diameter sheared. Inch.	Double Sectional Area. Sq. Inch.	Shearing Load per square inch. Lbs.	Shearing Load per square inch. Tons.	Nature of Fracture.
First lot of 1·1 inch Bar.	9050–1	0·800	1·005	58,020	25·90	
	9050–2	0·800	1·005	58,580	26·15	
	9050–3	0·800	1·005	58,160	25·97	
	9050–4	0·800	1·005	58,370	26·05	
			Means	**58,282**	**26·02**	
Second lot of 1·1 inch Bar.	10674–1	0·803	1·013	57,170	25·52	Silky.
	10674–2	0·800	1·005	49,450	22·08	Silky.
	10674–3	0·800	1·005	53,840	24·04	Silky.
	10674–4	0·801	1·007	53,380	23·83	Silky.
			Means	**53,460**	**23·87**	
Averages of two lots of 1·1 inch Bar				**55,871**	**24·94**	*Averages of Bars.*
Rivets from first lot of 1·1 inch Bar.	10682–1	0·805	1·018	43,810	19·56	Silky; reedy.
	10682–2	0·805	1·018	43,940	19·62	Silky.
	10682–3	0·810	1·031	45,140	20·15	
	10682–4	0·810	1 031	45,140	20·15	Silky.
	Averages of 1·1 inch Rivets			**44,507**	**19·87**	*Averages of Rivets.*

TABLE XXXVIII. (*continued from preceding page*)

Series XIV. *Shearing Resistance of Steel Rivet-Bars and Rivets.*

Lot.	Test number.	Diameter sheared.	Double Sectional Area.	Shearing Load per square inch.		Nature of Fracture.
		Inch.	Sq. Inch.	Lbs.	Tons.	
First lot of 1·3 inch Bar.	9049–1	0·798	1·000	55,090	24·59	
	9049–2	0·802	1·010	56,000	25·00	
	9049–3	0·798	1·000	55,160	24·62	
	9049–4	0·800	1·005	55,170	24·63	
			Means	**55,355**	**24·71**	
Second lot of 1·3 inch Bar.	10675–1	0·801	1·007	60,130	26·84	Silky; partly granular.
	10675–3	0·801	1·007	49,350	22·03	Silky; partly crystalline.
	10675–4	0·801	1·007	62,500	27·90	Silky; slightly granular at centre.
	10675–6	0·801	1·007	49,010	21·88	
			Means	**55,247**	**24·66**	
Averages of two lots of 1·3 inch Bar				**56,818**	**24·68**	*Averages of Bars.*
Rivets from first lot of 1·3 inch Bar.	10681–1	0·812	1·036	56,080	25·04	Silky.
	10681–2	0·805	1·018	58,450	26·10	Silky.
	10681–3	0·805	1·018	59,200	26·43	Silky.
	10681–4	0·804	1·015	52,970	23·65	Silky.
			Means	**56,675**	**25·30**	
Rivets from second lot of 1·3 inch Bar.	10678–1	0·805	1·018	49,710	22·20	Silky; one end a little granular at centre.
	10678–2	0·810	1·031	52,750	23·55	Silky.
	10678–3	0·806	1·021	49,020	21·88	Silky.
			Means	**50,493**	**22·54**	
Averages of two lots of 1·3 inch Rivets				**53,584**	**23·92**	*Averages of Rivets.*

TABLE XXXVIII. (*continued from preceding page*)

Series XIV. *Shearing Resistance of Steel Rivet-Bars and Rivets.*

Lot.	Test number.	Diameter sheared. Inch.	Double Sectional Area. Sq. Inch.	Shearing Load per square inch. Lbs.	Shearing Load per square inch. Tons.	Nature of Fracture.
First lot of 1·6 inch Bar.	9048–1	0·800	1·005	51,890	23·16	
	9048–2	0·800	1·005	51,340	22·92	
	9048–3	0·798	1·000	52,080	23·25	
	9048–4	0·800	1·005	51,760	23·10	
			Means	**51,765**	**23·11**	
Second lot of 1·6 inch Bar.	10686–3	0·792	0·9854	49,300	22·01	Silky; slightly granular in centre.
	10686–4	0·792	0·9854	49,510	22·10	Silky; crystalline-granular in centre.
	10686–5	0·792	0·9854	54,050	24·13	Silky.
	10686–6	0·792	0·9854	49,660	22·17	Silky; crystalline-granular in centre.
			Means	**50,630**	**22·60**	
Averages of two lots of 1·6 *inch Bar*				**51,197**	**22·85**	*Averages of Bars.*
Rivets from first lot of 1·6 inch Bar.	10680–1	0·802	1·010	54,330	24·26	Silky.
	10680–2	0·810	1·031	51,110	22·82	Silky; crystalline-granular at centre.
	10680–3	0·816	1·046	56,010	25·01	Silky.
			Means	**53,483**	**24·03**	
Rivets from second lot of 1·6 inch Bar.	10677–1	0·808	1·026	48,300	21·56	Silky at one end; finely crystalline at centre.
	10677–2	0·807	1·023	49,130	21·93	Silky.
	10677–3	0·807	1·023	50,630	22·61	Silky.
			Means	**49,353**	**22·03**	
Averages of two lots of 1·6 *inch Rivets*				**51,418**	**23·03**	*Averages of Rivets.*

TABLE XXXVIII. (*concluded from page* 560)

Series XIV. *Shearing Resistance of Steel Rivet-Bars and Rivets.*

Lot.	Test number.	Diameter sheared. Inch.	Double Sectional Area. Sq. inch.	Shearing Load per square inch. Lbs.	Tons.	Nature of Fracture.
First lot of 1·75 inch Bar.	9047–1	0·800	1·005	54,290	24·24	
	9047–2	0·798	1·000	52,500	23·44	
	9047–3	0·798	1·000	52,570	23·47	
	9047–4	0·800	1·005	51,890	23·16	
			Means	**52,812**	**23·58**	
Second lot of 1·75 inch Bar.	10685–3	0·792	0·9854	52,420	23·40	One end crystalline, the other silky.
	10685–4	0·792	0·9854	53,700	23·97	Silky.
	10685–5	0·792	0·9854	51,150	22·83	Silky.
	10685–6	0·792	0·9854	51,570	23·02	Silky, slightly granular at centre.
			Means	**52,210**	**23·30**	
Averages of two lots of 1·75 *inch Bar*				**52,511**	**23·44**	*Averages of Bars.*
Rivets from first lot of 1·75 inch Bar.	10679–1	0·810	1·031	52,950	23·64	Silky.
	10679–2	0·810	1·031	53,770	24·00	Silky.
	10679–3	0·810	1·031	53,900	24·06	Silky, a little granular at centre.
			Means	**53,540**	**23·90**	
Rivets from second lot of 1·75 inch Bar.	10676	0·809	1·028	51,000	22·77	Silky.
			Means	**51,000**	**22·77**	
Averages of two lots of 1·75 *inch Rivets*				**52,270**	**23·33**	*Averages of Rivets.*

TABLE XXXIX, *see next page.*

TABLE XXXIX. (*see continuation on opposite page*)

SERIES XIV. *Double-Riveted Lap and Butt Joints*

Nature of Joint, Mode of Riveting, and Pressure on Rivets.	Test number, and Mark on piece.	*See Plates 105 and 106.* Dimensions. Thickness. Inch.	Breadth. Inches.	Visible Slip began. Tons.	Total Breaking Load. Tons.	Tearing Area. Sq. Ins.	Tensile Stress per sq. inch. Tons.
LAP-JOINTS. *Hand-riveted.*	13037 A 1	0·400	11·6	29·26	86·20	3·348	25·74
	13038 A 2	0·404	11·6	31·15	87·34	3·381	25·83
	13039 A 3	0·397	11·6	25·05	89·34	3·323	26·88
	See Figs. 1 *to* 3.		Means	**28·48**	**87·63**		**26·15**
		Tensile strength per square inch of original plate					25·57
LAP-JOINTS. *Machine-riveted, 30 to 35 tons.*	13040 B 1	0·400	11·6	41·66	82·65	3·348	24·68
	13041 B 2	0·399	11·6	37·64	87·16	3·339	26·10
	13042 B 3	0·403	11·6	32·52	88·82	3·373	26·33
	See Figs. 1 *to* 3.		Means	**37·27**	**86·21**		**25·70**
		Tensile strength per square inch of original plate					24·94
BUTT-JOINTS. *Machine-riveted, 30 to 35 tons.*	13043 C 1	0·367	11·0	59·77	85·90	3·002	28·61
	13044 C 2	0·378	11·0	61·63	80·16	3·092	25·92
	13045 C 3	0·388	11·0	54·52	79·64	3·174	25·09
	See Figs. 4 *to* 6.		Means	**58·64**	**81·90**		**26·54**
		Tensile strength per square inch of original plate					26·31
LAP-JOINTS. *Hand-riveted.*	13046 D 1	0·752	12·39	50·42	136·5	5·993	22·78
	13047 D 2	0·751	12·37	49·47	168·2	5·971	28·17
	13048 D 3	0·745	12·37	40·23	164·7	5·924	27·82
	See Figs. 7 *to* 9.		Means	**46·71**	**156·4**		**26·26**
		Tensile strength per square inch of original plate					27·82
LAP-JOINTS. *Machine-riveted, 60 to 80 tons.*	13049 E 1	0·750	12·40	43·29	136·9	5·980	22·89
	13050 E 2	0·743	12·40	52·05	139·5	5·930	23·52
	13051 E 3	0·745	12·38	54·62	173·8	5·930	29·30
	See Figs. 7 *to* 9.		Means	**47·79**	**150·1**		**25·27**
		Tensile strength per square inch of original plate					28·37
BUTT-JOINTS. *Machine-riveted, 60 to 80 tons.*	13052 F 1	0·749	13·21	108·10	191·8	7·408	25·89
	13053 F 2	0·748	13·20	86·00	190·1	7·390	25·73
	13054 F 3	0·751	13·20	85·30	188·1	7·420	25·35
	See Figs. 10 *to* 12.		Means	**93·13**	**190·0**		**25·66**
		Tensile strength per square inch of original plate					28·73

(*see continuation on opposite page*)

(continued from opposite page) TABLE XXXIX.

in ⅜-inch and ¾-inch Steel Plate, Hand-riveted and Machine-riveted.

Shearing Area.	Shearing Stress per sq. inch.	Bearing Area.	Bearing Pressure per sq. inch.	Load per inch breadth when visible slip began.	Breaking Load per inch breadth of nominal thickness. On original Plate.	Breaking Load per inch breadth of nominal thickness. At Joint.	Efficiency of Joint.	P = Plate tore. R = Rivets sheared.
Sq. Ins.	Tons.	Sq. Ins.	Tons.	Tons.	Tons.	Tons.	Per cent.	
4·092	21·07	2·56	33·67	2·36	9·64	6·96	72·2	P
4·092	21·34	2·61	33·46	2·57	9·45	6·98	73·9	P
4·092	21·82	2·56	34·90	2·04	9·67	7·27	75·2	P
	21·41		**34·01**	**2·32**	**9·58**	**7·07**	**73·8**	
				Eight Rivets, holes 0·8 *inch diameter.*				
4·092	20·20	2·58	32·04	3·37	8·87	6·68	75·3	P
4·092	21·30	2·57	33·84	3·05	9·61	7·06	73·5	P
4·092	21·70	2·60	34·16	2·61	9·58	7·12	74·3	P
	21·07		**33·31**	**3·01**	**9·35**	**6·95**	**74·3**	
				Eight Rivets, holes 0·8 *inch diameter.*				
6·24	13·77	2·07	41·52	5·55	10·37	7·98	76·9	P
6·24	12·85	2·13	37·64	5·56	10·03	7·23	72·1	P
6·24	12·76	2·19	36·40	4·79	9·20	6·99	76·0	P
	13·13		**38·52**	**5·30**	**9·87**	**7·40**	**75·0**	
				Eight Rivets, holes 0·7 *inch diameter.*				
7·68	17·77	6·65	20·51	4·06	[21·27]	10·99	[51·7]	R
7·68	21·91	6·64	25·31	3·99	21·18	13·58	64·1	P
7·68	21·43	6·59	25·00	3·27	20·55	13·40	65·2	P
	20·37		**23·94**	**3·77**	**20·86**	**12·66**	**64·65**	
				Eight Rivets, holes 1·1 *inch diameter.*				
7·68	17·81	6·63	20·65	3·49	[21·27]	11·04	[52·0]	R
7·68	18·15	6·57	21·23	4·22	[21·27]	11·33	[53·4]	R
7·68	22·61	6·59	26·37	4·44	21·28	14·13	66·4	P
	19·52		**22·42**	**4·05**	**21·28**	**12·17**	**66·4**	
				Eight Rivets, holes 1·1 *inch diameter.*				
11·53	16·64	4·97	38·59	8·19	21·55	14·54	67·5	P
11·53	16·49	4·96	38·33	6·53	21·79	14·42	66·2	P
11·53	16·31	4·98	37·78	6·48	21·32	14 23	66·7	P
	16·45		**38·23**	**7·07**	**21·55**	**14·39**	**66·8**	
				Six Rivets, holes 1·1 *inch diameter.*				

TABLE XL. (*see continuation on opposite page*)

SERIES XIV. *Double-Riveted Lap and Butt Joints*

Nature of Joint, Mode of Riveting, and Pressure on Rivets.	Test number, and Mark on piece.	See Plates 107 to 109. Dimensions. Thickness. Inch.	Breadth. Inches.	Visible Slip began. Tons.	Total Breaking Load. Tons.	Tearing Area. Sq. Ins.	Tensile Stress per sq. inch. Tons.
LAP-JOINTS. *Machine-riveted, 100 tons.*	13055 G 1	0·742	16·40	79·20	241·1	8·620	28·00
	13056 G 2	0·734	16·40	61·93	240·4	8·530	28·19
	13057 G 3	0·739	16·40	69·74	242·4	8·586	28·23
	See Figs. 13 *to* 15.		**Means**	**70·29**	**241·3**		**28·14**
		Tensile strength per square inch of original plate					28·75
BUTT-JOINTS. *Machine-riveted, 100 tons.*	13058 H 1	0·753	12·60	81·60	178·1	7·085	25·14
	13059 H 2	0·757	12·60	84·00	187·5	7·123	26·33
	13060 H 3	0·756	12·60	92·40	189·7	7·114	26·67
	See Figs. 16 *to* 18.		**Means**	**86·00**	**185·1**		**26·05**
		Tensile strength per square inch of original plate					28·65
LAP-JOINTS. *Machine-riveted, 100 tons.*	13061 K 1	0·992	12·60	60·11	223·2	7·320	30·49
	13062 K 2	0·966	12·60	60·90	222·3	7·128	31·18
	13063 K 3	0·979	12·60	66·40	224·1	7·226	31·02
	See Figs. 19 *to* 21.		**Means**	**62·47**	**223·2**		**30·90**
		Tensile strength per square inch of original plate					27·67
LAP-JOINTS. *Machine-riveted, 100 tons.*	13064 L 1	1·001	10·50		189·3	7·010	27·01
	13065 L 2	0·973	10·50	67·40	191·8	6·810	28·16
	13066 L 3	1·005	10·50	64·50	194·2	7·035	27·61
	See Figs. 22 *to* 24.		**Means**	**65·95**	**191·8**		**27·59**
		Tensile strength per square inch of original plate					27·49
BUTT-JOINTS. *Machine-riveted, 100 tons.*	13067 M 1	0·991	10·20	92·05	197·5	7·520	26·27
	13068 M 2	0·991	10·20	84·71	199·3	7·520	26·51
	13069 M 3	0·990	10·20	86·15	196·4	7·510	26·15
	See Figs. 25 *to* 27.		**Means**	**87·64**	**197·7**		**26·31**
		Tensile strength per square inch of original plate					28·23

(*see continuation on opposite page*)

(*continued from opposite page*) TABLE XL.

in $\frac{3}{4}$*-inch and* 1*-inch Steel Plate, with large Rivets, Machine-riveted.*

(*continued from opposite page*)

Shearing Area.	Shearing Stress per sq. inch.	Bearing Area.	Bearing Pressure per sq. inch.	Load per inch breadth when visible slip began.	Breaking Load per inch breadth of nominal thickness. On original Plate.	Breaking Load per inch breadth of nominal thickness. At Joint.	Efficiency of Joint.	P = Plate tore. R = Rivets sheared.
Sq. Ins.	Tons.	Sq. Ins.	Tons.	Tons.	Tons.	Tons.	Per cent.	
11·96	20·18	7·09	34·00	4·88	[21·56]	14·86	[69·0]	R
11·96	20·10	7·01	34·29	3·85	[21·56]	14·98	[69·5]	R
11·96	20·27	7·06	34·34	4·31	21·56	15·00	69·6	P
	20·18		**34·21**	**4·35**	**21·56**	**14·95**	**69·6**	
				Six Rivets, holes 1·6 *inch diameter.*				
15·94	11·17	4·79	37·18	6·45	21·12	14·08	66·7	P
15·94	11·76	4·82	38·90	6·60	21·73	14·74	67·8	P
15·94	11·90	4·82	39·36	7·27	21·62	14·94	69·1	P
	11·61		**38·48**	**6·77**	**21·49**	**14·59**	**67·9**	
				Four Rivets, holes 1·6 *inch diameter.*				
10·70	20·86	10·35	21·57	4·81	27·77	17·86	64·3	P
10·70	20·78	10·08	22·05	4·94	27·89	18·26	65·5	P
10·70	20·94	10·22	21·93	5·38	27·35	18·17	66·4	P
	20·86		**21·85**	**5·04**	**27·67**	**18·10**	**65·4**	
				Eight Rivets, holes 1·3 *inch diameter.*				
9·62	19·68	7·00	27·04		26·62	18·01	67·7	P
9·62	19·94	6·81	28·16	6·60	28·04	18·70	66·7	P
9·62	20·19	7·03	27·63	6·11	27·82	18·40	66·1	PP*
	19·94		**27·61**	**6·24**	**27·49**	**18·37**	**66·8**	
				Four Rivets, holes 1·75 *inch diameter.*				
10·70	18·46	5·17	38·22	9·11	28·00	19·55	69·8	P
10·70	18·62	5·17	38·55	8·32	28·41	19·72	69·4	P
10·70	18·35	5·17	38·00	8·53	28·27	19·45	68·8	P
	18·48		**38·26**	**8·65**	**28·23**	**19·57**	**69·3**	
				Four Rivets, holes 1·3 *inch diameter.*				

* Both plates tore.

TABLE XLI.—*Comparative Results of Experiments in* Series XI *to* XIV.

Double-Riveted Lap and Butt Joints in Steel Plates.

Series.	Table.	Lap or Butt Joint.	Thickness of Plate. Inch.	Diameter of Rivet Holes. Inch.	Ratio of Pitch to Diameter.	Riveted by Hand or Machine.	Pressure in closing rivet. Tons.	Assumed Excess Strength. Per cent.	Comparative Efficiency of Joint. Per cent.
XI	XXIX	Lap	$\frac{3}{8}$	0·8	3·62	Hand		4·3	75·2
XIV A	XXXIX	,,	,,	,,	,,	,,		,,	75·2
XII	XXIX	,,	,,	,,	,,	Machine	35	,,	75·1
XIV B	XXXIX	,,	,,	,,	,,	,,	35	,,	75·5
XI to XIII	XXX	Butt	$\frac{3}{8}$	0·7	3·93	Hand and Machine	35	2·7	76·7
XIV C	XXXIX	,,	,,	,,	,,	Machine	35	,,	76·5
XI	XXXI	Lap	$\frac{3}{4}$	1·1	2·82	Hand		6·0	68·5
XIV D	XXXIX	,,	,,	,,	,,	,,		,,	68 0
XII	XXXI	,,	,,	,,	,,	Machine	35	,,	69·1
XIV E	XXXIX	,,	,,	,,	,,	,,	70	,,	68·0
XIV G	XL	,,	,,	1·6	3·41	,,	100	4·0	73·6
XI to XIII	XXXII	Butt	$\frac{3}{4}$	1·1	4·00	Hand and Machine	35	1·8	72·4
XIV F	XXXIX	,,	,,	,,	,,	Machine	70	,,	76·0
XIV H	XL	,,	,,	1·6	3·94	,,	100	2·0	76·1
XIV K	XL	Lap	1	1·3	2·42	Machine	100	7·5	63·0
XIV L	XL	,,	,,	1·75	3·00	,,	,,	5·4	70·2
XIV M	XL	Butt	,,	1·3	3·92	,,	,,	2·1	76·1

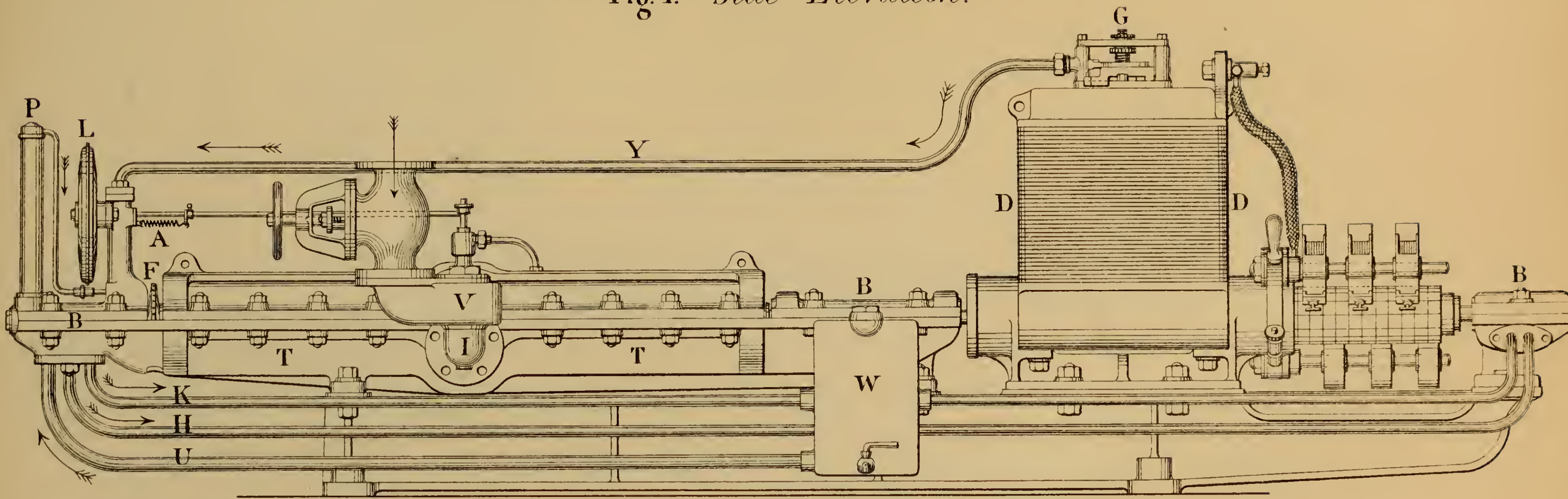
INDEX.

1888.

COMPOUND STEAM TURBINE.

Turbo-Electric Generator for 200 ampères at 80 volts, 25 H.P.

Fig. 1. *Side Elevation.*



Scale 1/16th

12 Inches 6 0 1 2 3 4 5 6 7 8 Feet

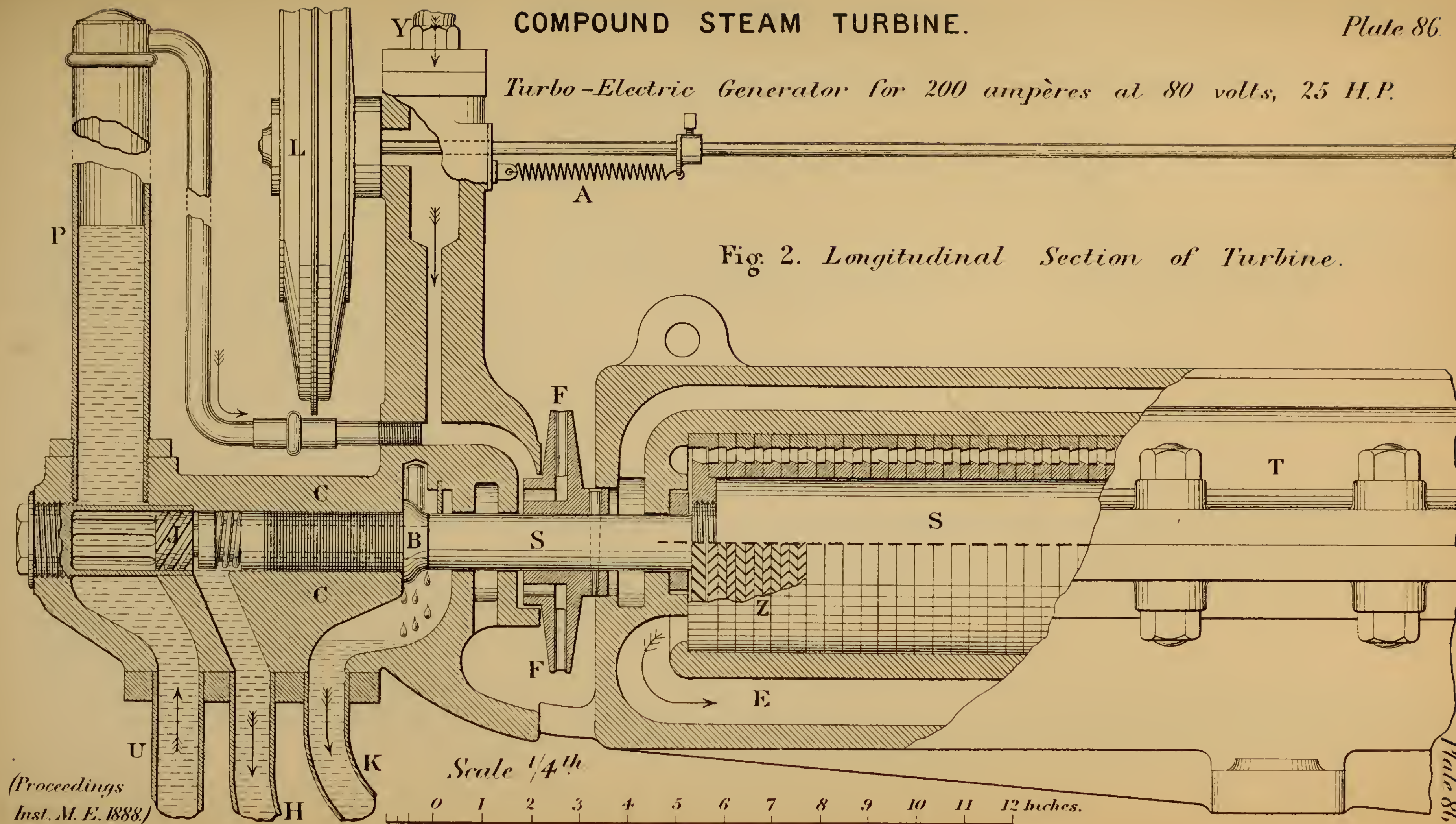
(Proceedings Inst. M.E. 1888.)

Plate 85.

COMPOUND STEAM TURBINE.

Turbo-Electric Generator for 200 ampères at 80 volts, 25 H.P.

Fig. 2. *Longitudinal Section of Turbine.*



(Proceedings Inst. M. E. 1888.)

Plate 86.

COMPOUND STEAM TURBINE.

Turbo-Electric Generator for 200 ampères at 80 volts, 25 H.P.

Electrical Control Governor. Scale 1/4 th

Fig. 3. Plan.

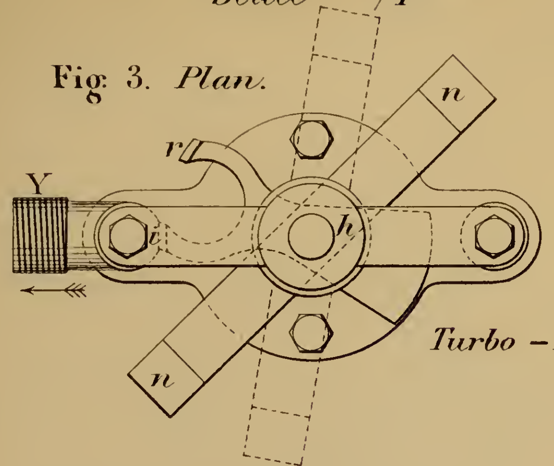
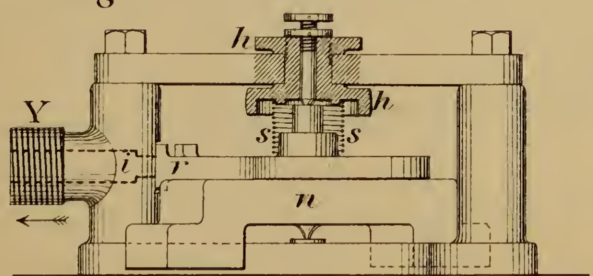


Fig. 4. Side Elevation.



(Proceedings Inst. M. E. 1888.) Scale 1/4 th

0 1 2 3 4 5 6 7 8 Inches.

Fig. 5. Winding of Armature. Scale 1/4 th

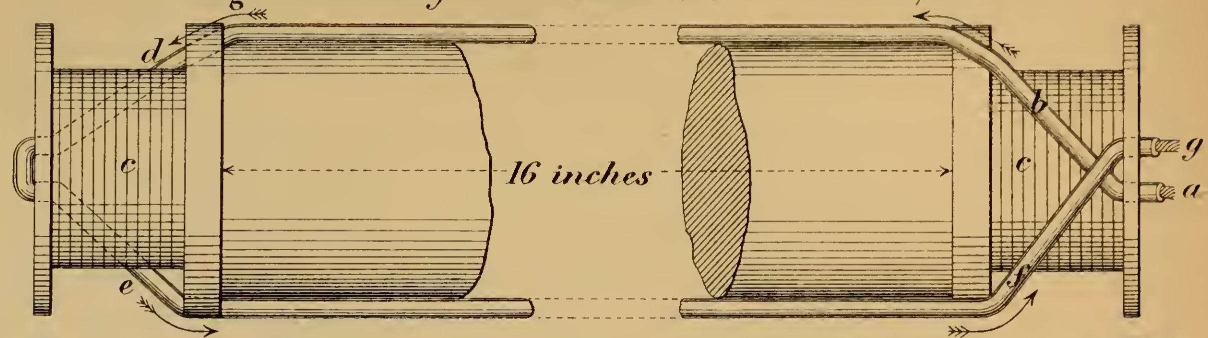


Fig. 6. Longitudinal Section of Bearing. Full size.

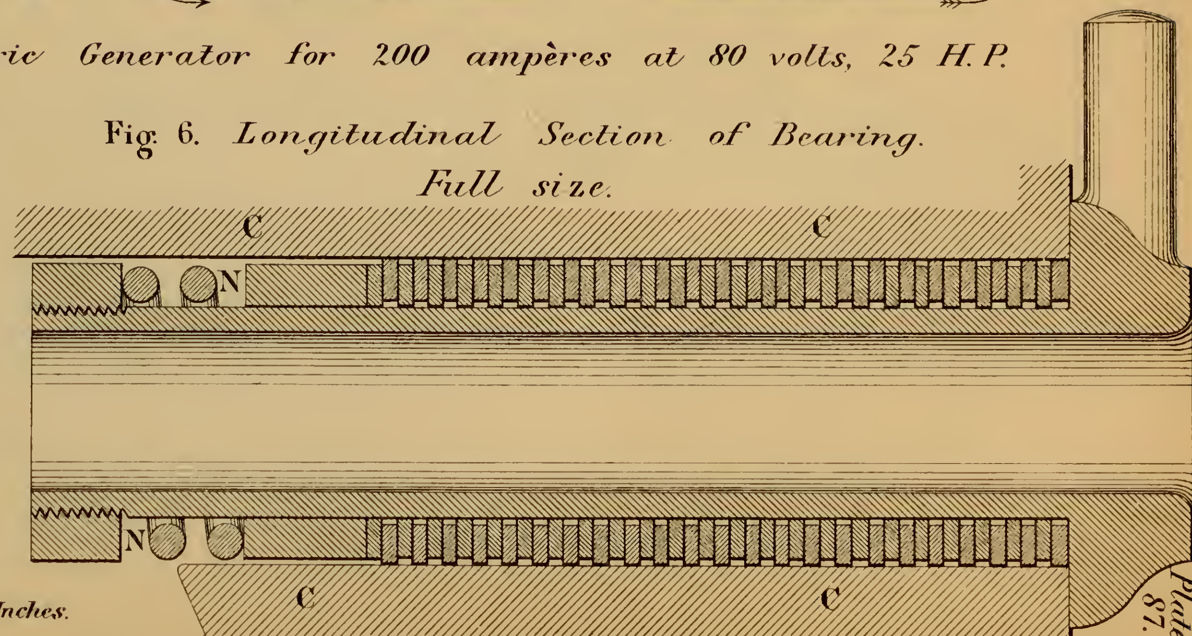
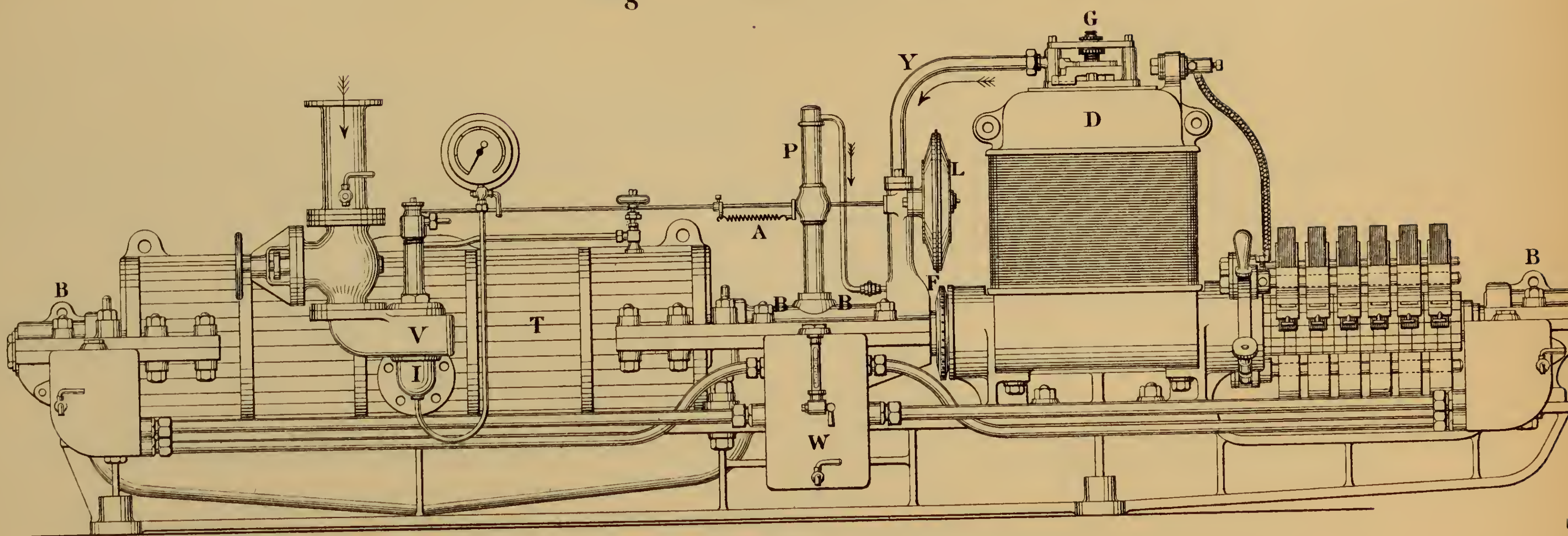


Plate 87.

COMPOUND STEAM TURBINE.

Turbo-Electric Generator for 400 ampères at 80 volts, 50 H.P.

Fig. 7. *Side Elevation.*



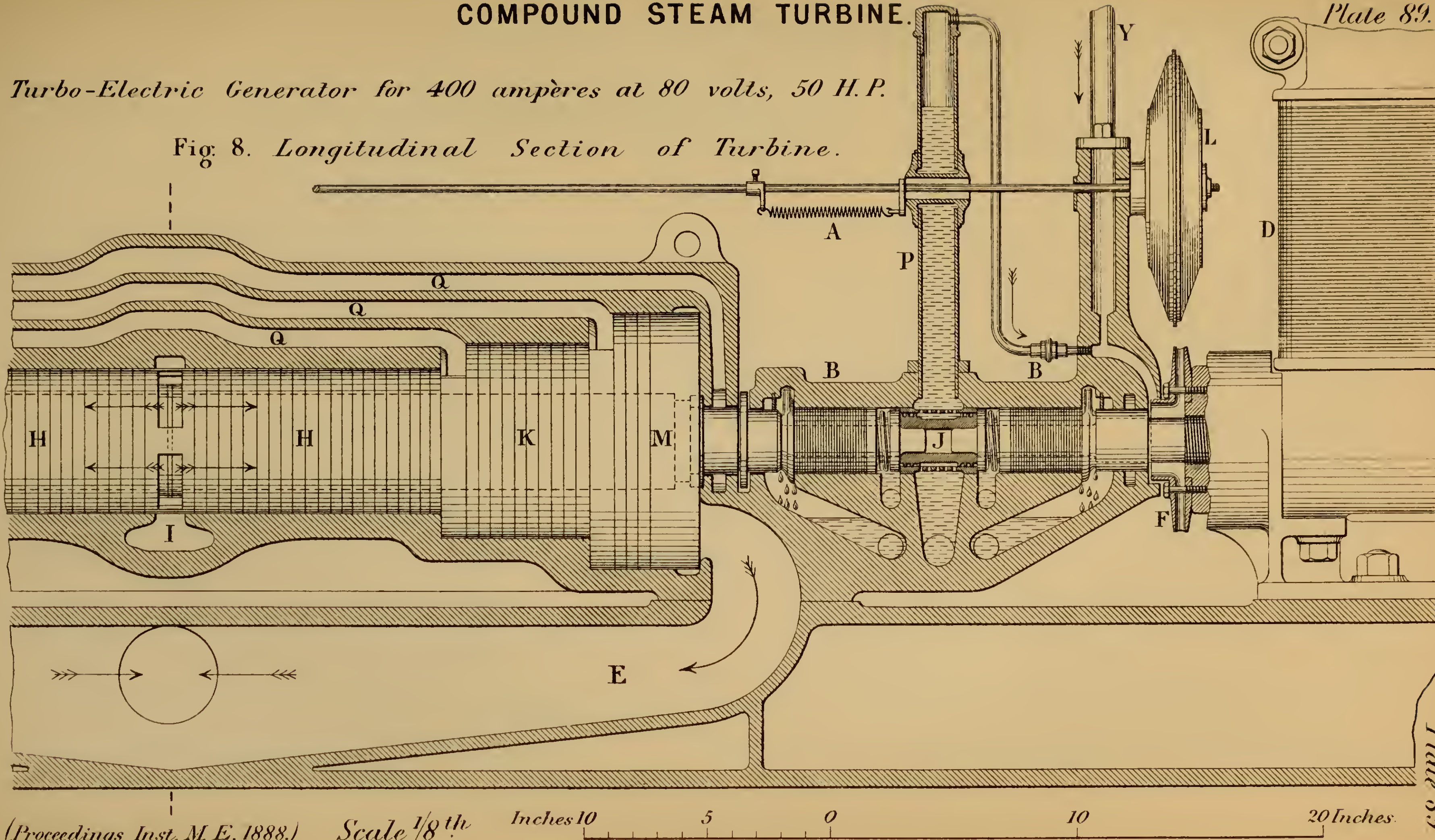
Scale 1/16th

(Proceedings Inst. M. E. 1888.)

COMPOUND STEAM TURBINE.

Turbo-Electric Generator for 400 ampères at 80 volts, 50 H. P.

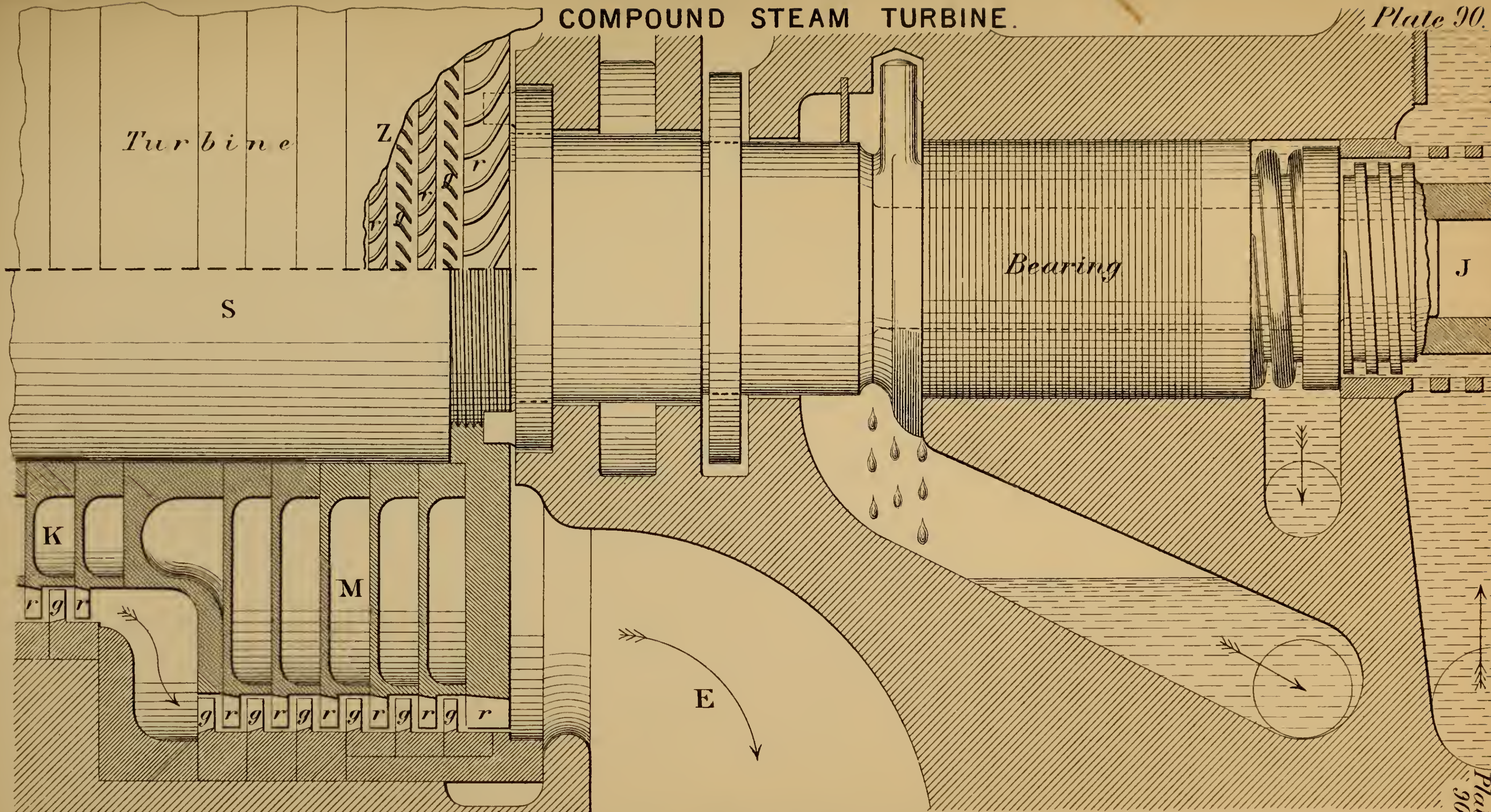
Fig. 8. *Longitudinal Section of Turbine.*



(*Proceedings Inst. M. E. 1888.*) *Scale 1/8th.*

Plate 89.

COMPOUND STEAM TURBINE.



(Proceedings Inst. M. E. 1888.)

Fig. 9. *Enlargement from Fig. 8. Scale half size.*

RATHMINES WATER WORKS.

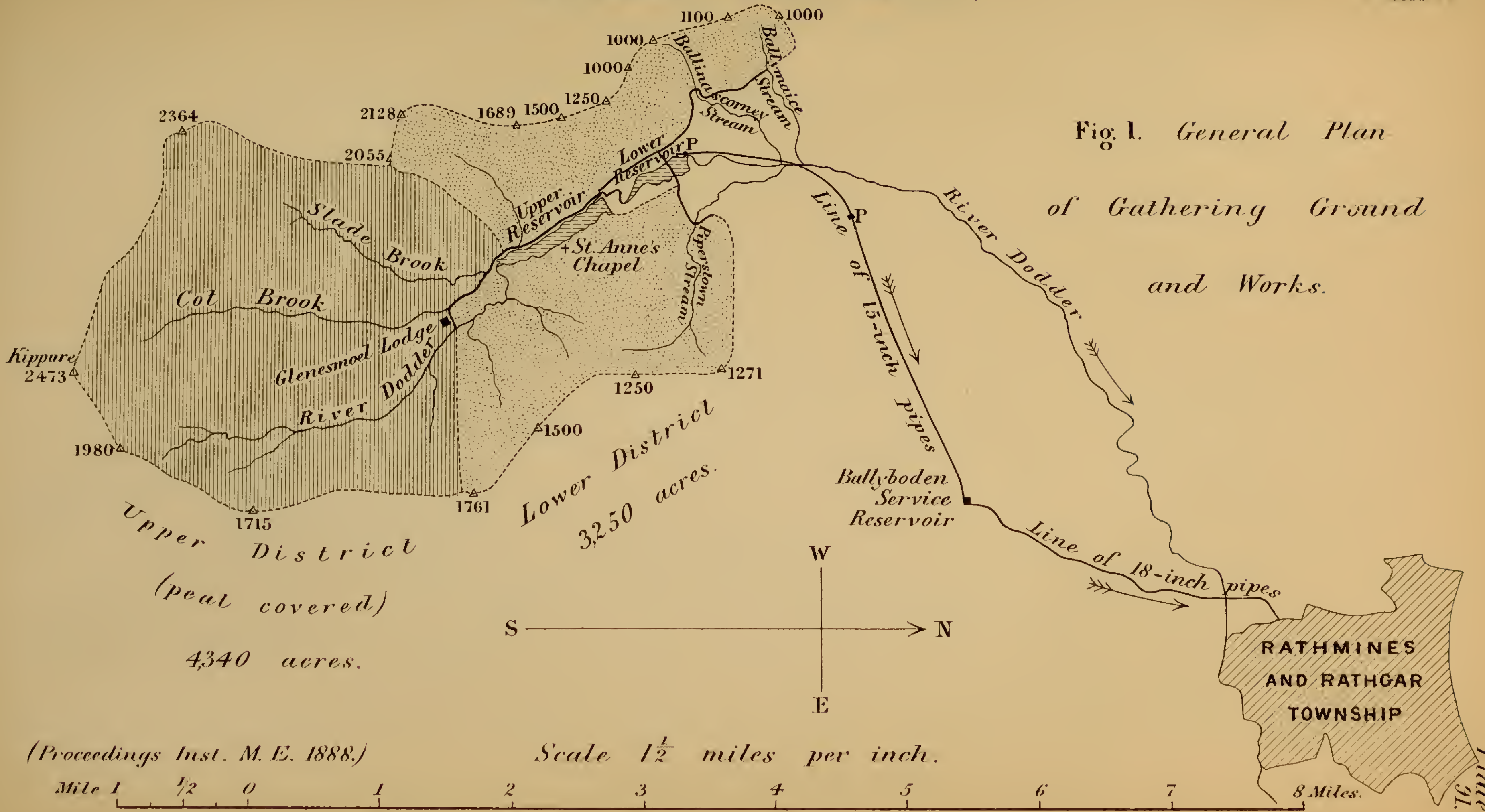


Fig. 1. General Plan of Gathering Ground and Works.

Scale $1\frac{1}{2}$ miles per inch.

(Proceedings Inst. M. E. 1888.)

RATHMINES WATER WORKS.

Plate 92.

Fig. 2. *Plan of Upper Reservoir.*

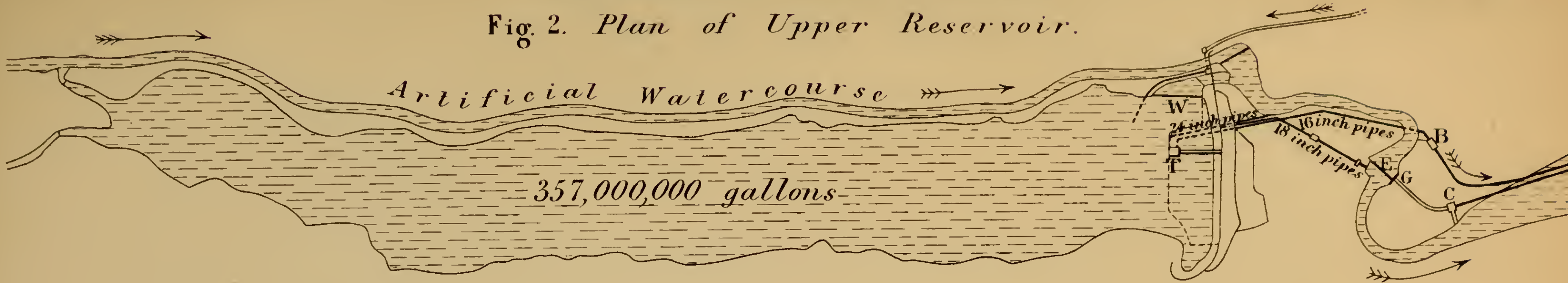
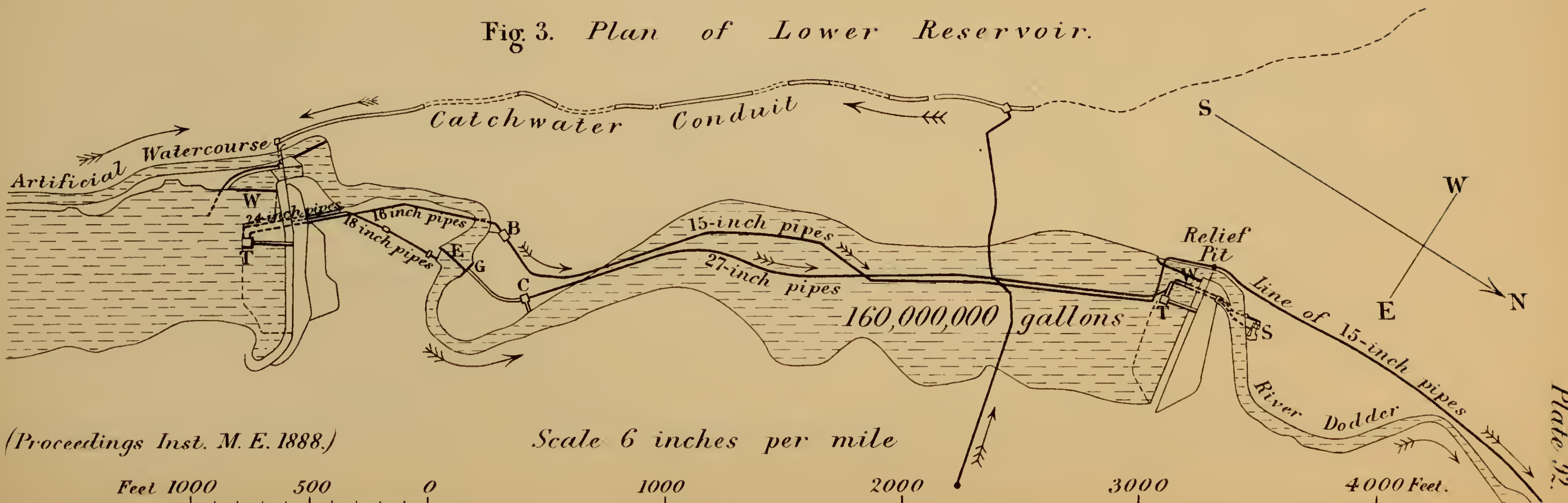


Fig. 3. *Plan of Lower Reservoir.*



(Proceedings Inst. M. E. 1888.)

Scale 6 inches per mile

Plate 92.

RATHMINES WATER WORKS.

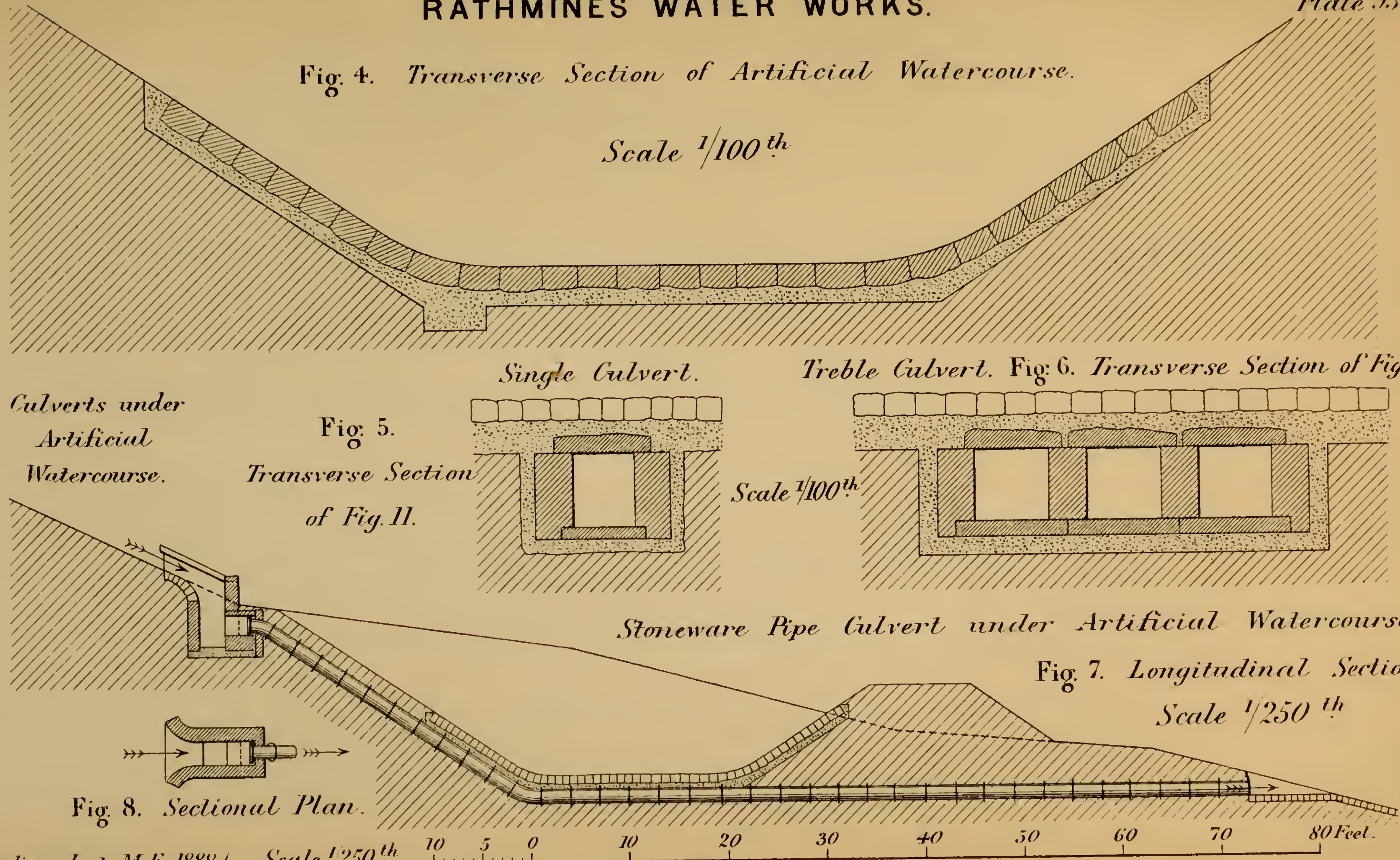


Fig. 4. *Transverse Section of Artificial Watercourse.*

Scale 1/100th.

Culverts under Artificial Watercourse.

Fig. 5. *Transverse Section of Fig. 11.*

Single Culvert.

Scale 1/100th.

Treble Culvert. Fig. 6. *Transverse Section of Fig. 9.*

Stoneware Pipe Culvert under Artificial Watercourse.

Fig. 7. *Longitudinal Section.*

Scale 1/250th.

Fig. 8. *Sectional Plan.*

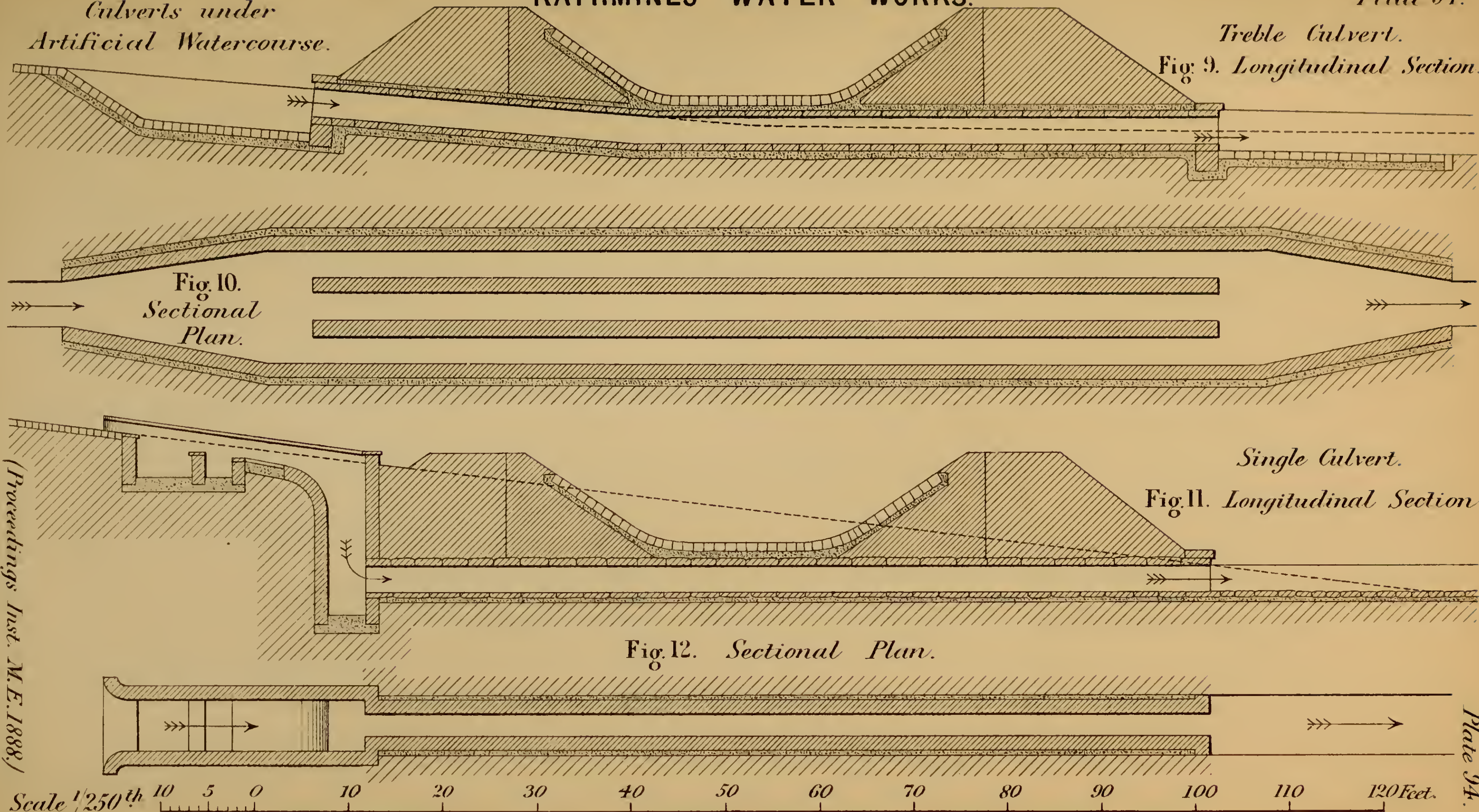
Scale 1/250th.

(Proceedings Inst. M. E. 1888.)

Plate 93.

RATHMINES WATER WORKS.

Culverts under Artificial Watercourse.



Treble Culvert.

Fig. 9. *Longitudinal Section.*

Fig. 10. *Sectional Plan.*

Single Culvert.

Fig. 11. *Longitudinal Section.*

Fig. 12. *Sectional Plan.*

Scale 1/250th.

Plate 94.

RATHMINES WATER WORKS.

Weir and By-Wash at Upper Reservoir.

Fig. 13. *Plan. See Plate 96.*

Scale 1/1200th.

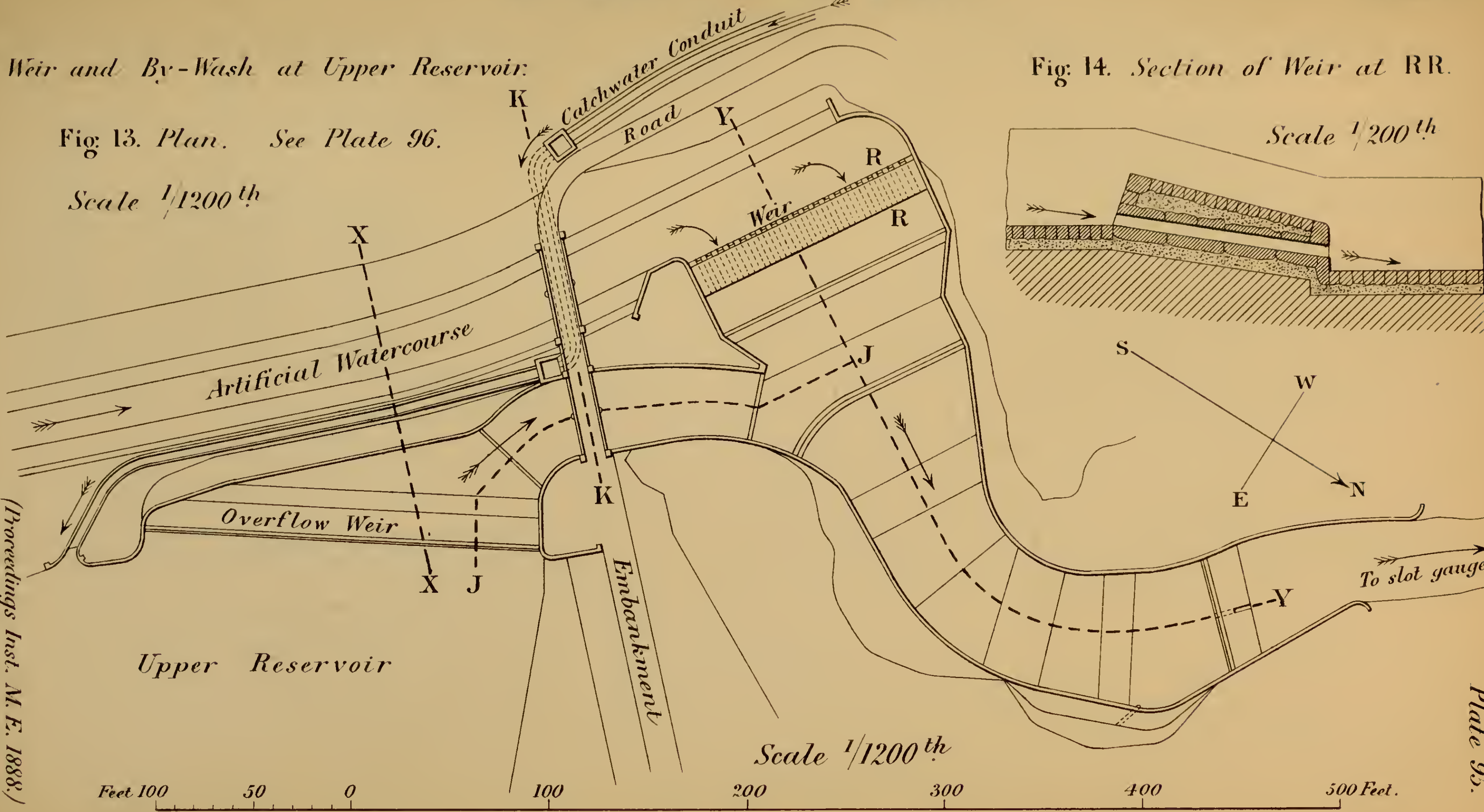


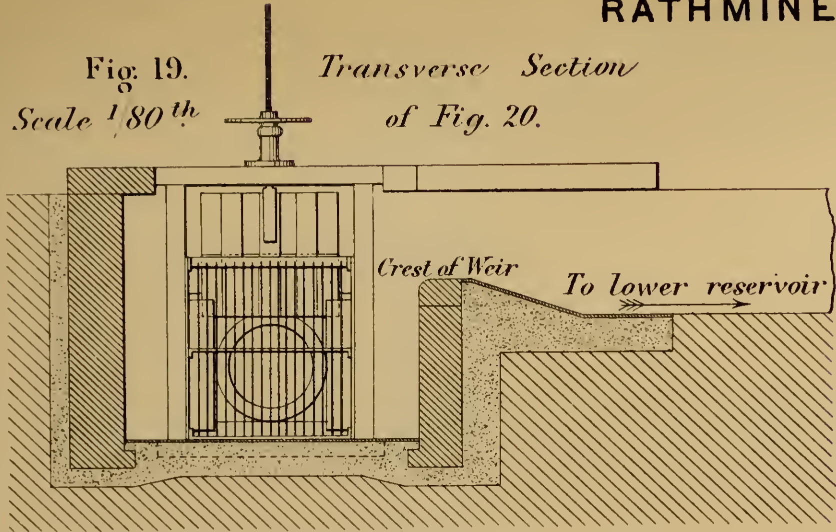
Fig. 14. *Section of Weir at RR.*

Scale 1/200th.

Plate 95.

RATHMINES WATER WORKS.

Fig: 19. Scale 1/80th. Transverse Section of Fig. 20.



Weirs and By-wash at Upper Reservoir. Scale 1/800th.

Fig. 15. Transverse Section on XX, Fig. 13.

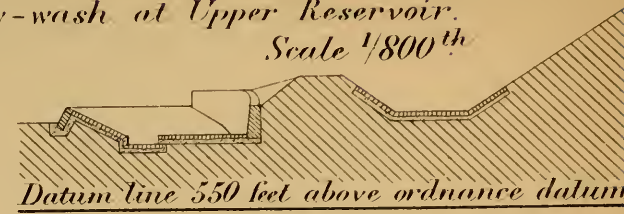


Fig: 16. Transverse Section on KK, Fig. 13.

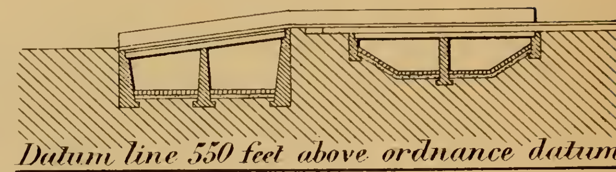


Fig: 17. Longitudinal Section on JJ, Fig. 13.

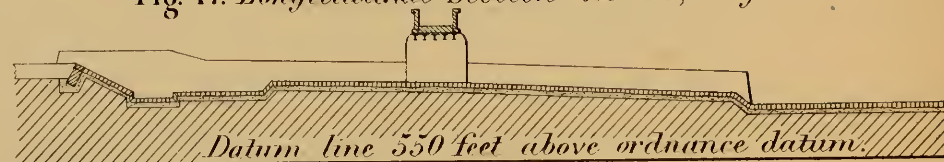


Fig: 18. Longitudinal Section on YY, Fig. 13.

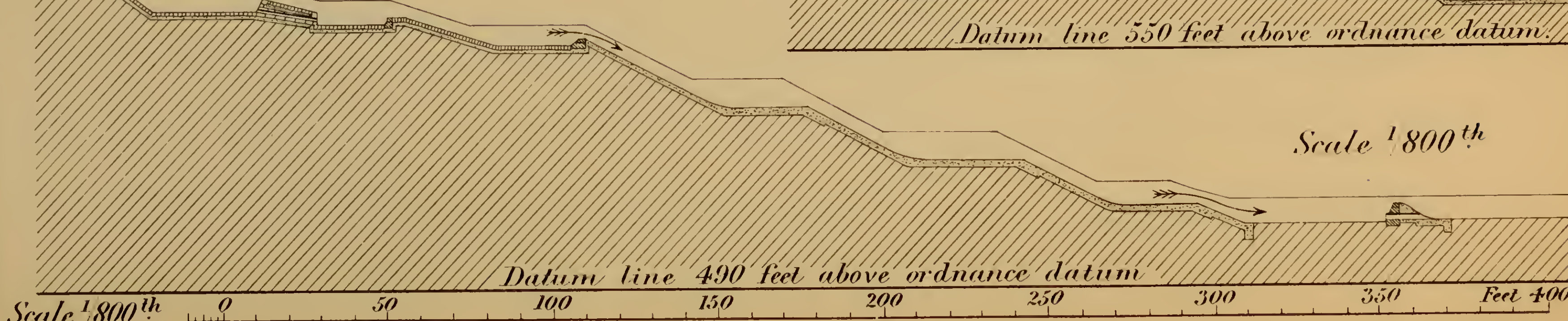
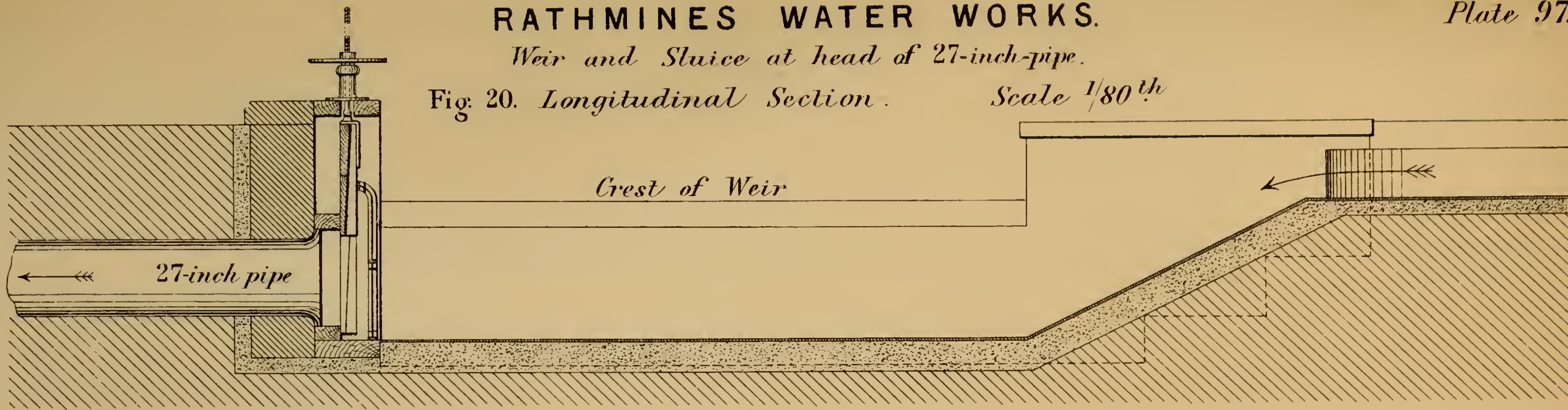


Plate 96.

RATHMINES WATER WORKS.

Weir and Sluice at head of 27-inch-pipe.

Fig. 20. *Longitudinal Section.* *Scale 1/80th.*



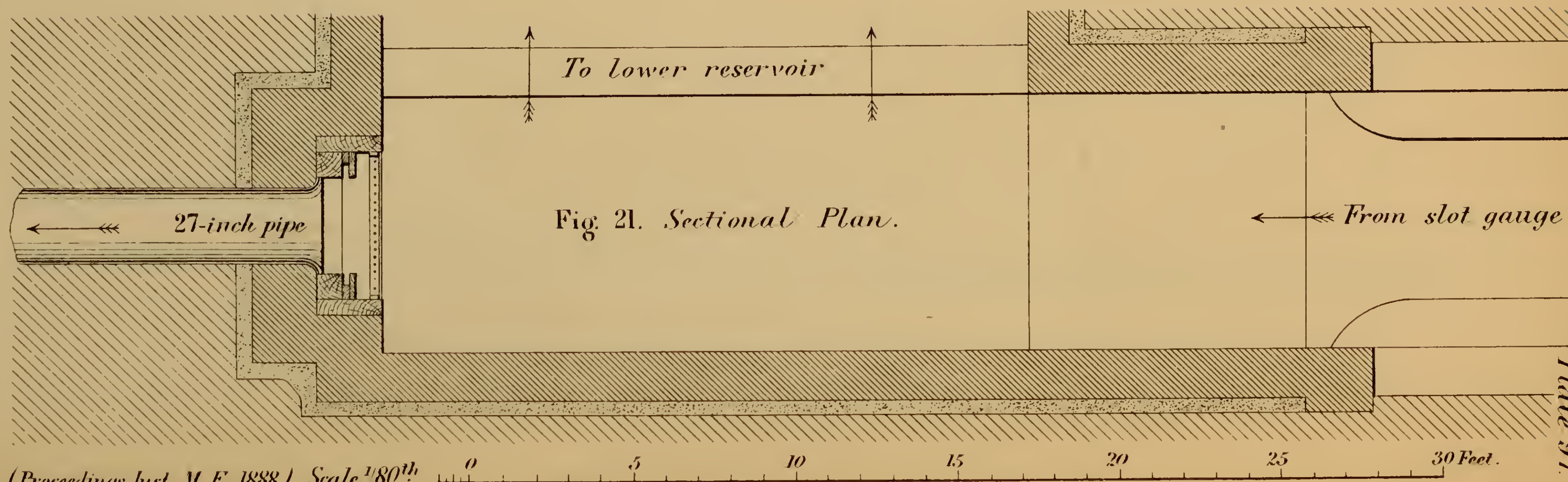


Fig. 21. *Sectional Plan.*

(Proceedings Inst. M. E. 1888.) Scale 1/80th.

Plate 97.

RATHMINES WATER WORKS.

Weir and Slot Gauge at head of Lower Reservoir.

Fig. 22. Plan.

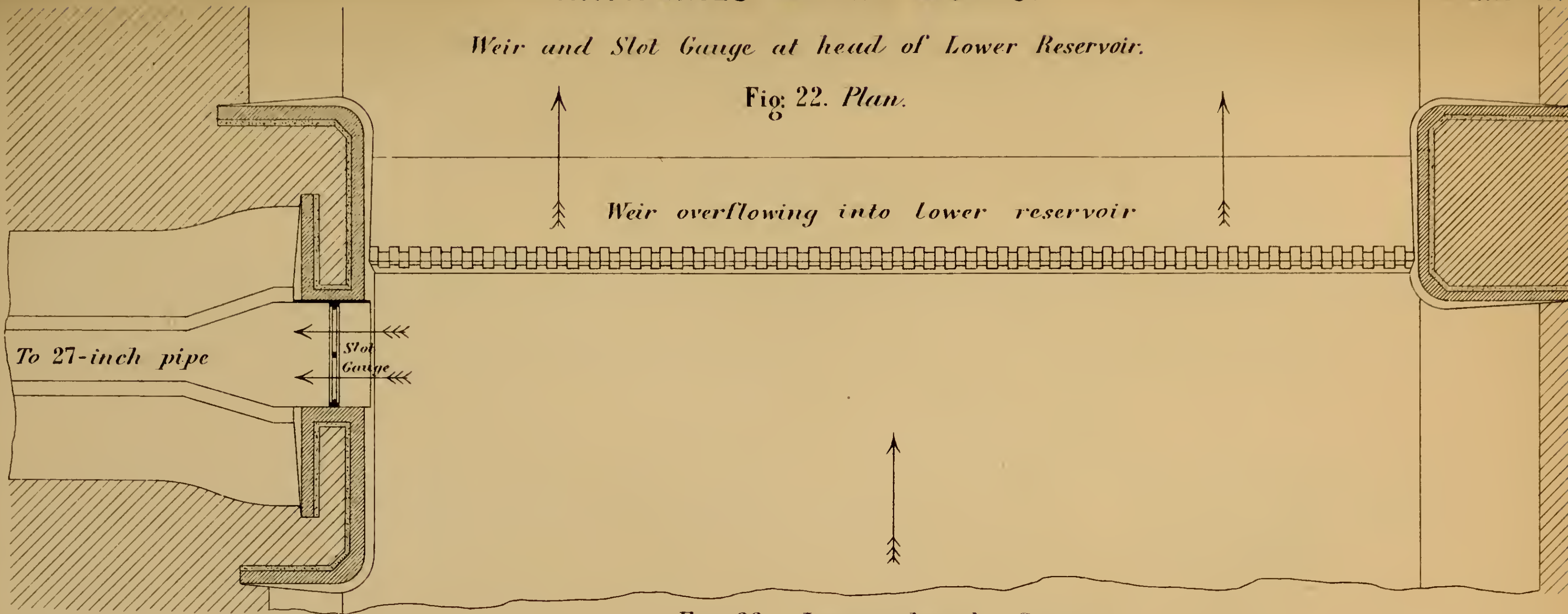
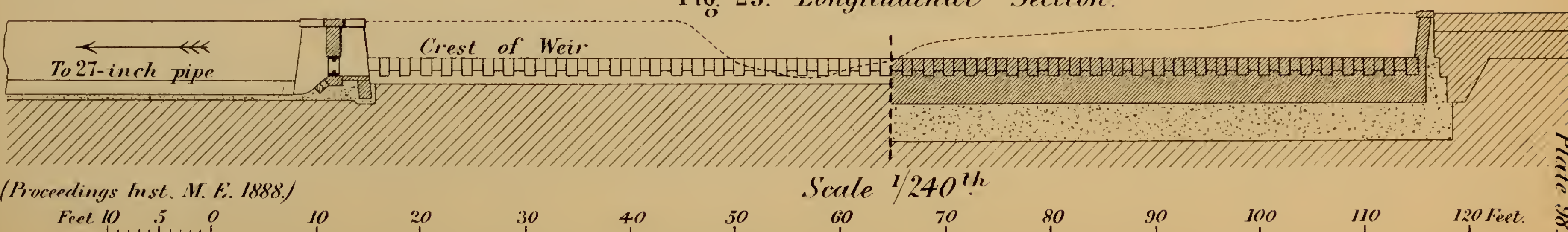


Fig. 23. Longitudinal Section.



Scale 1/240th.

(Proceedings Inst. M. E. 1888.)

Plate 98.

RATHMINES WATER WORKS.

Weir and Slot Gauge at head of Lower Reservoir Fig. 24. Transverse Section of Weir. Scale 1/80th

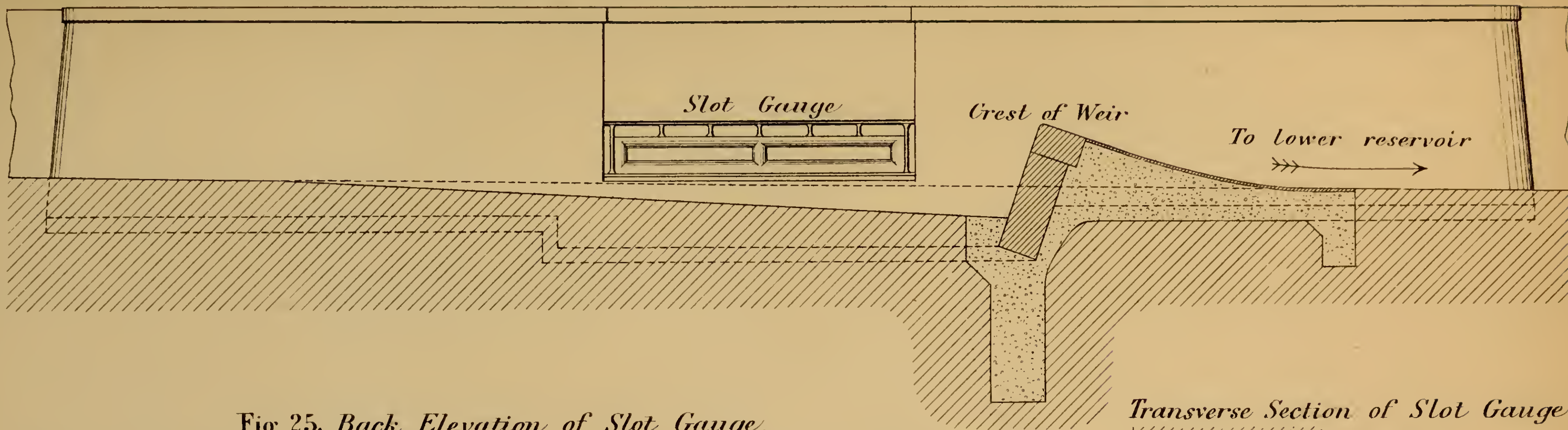
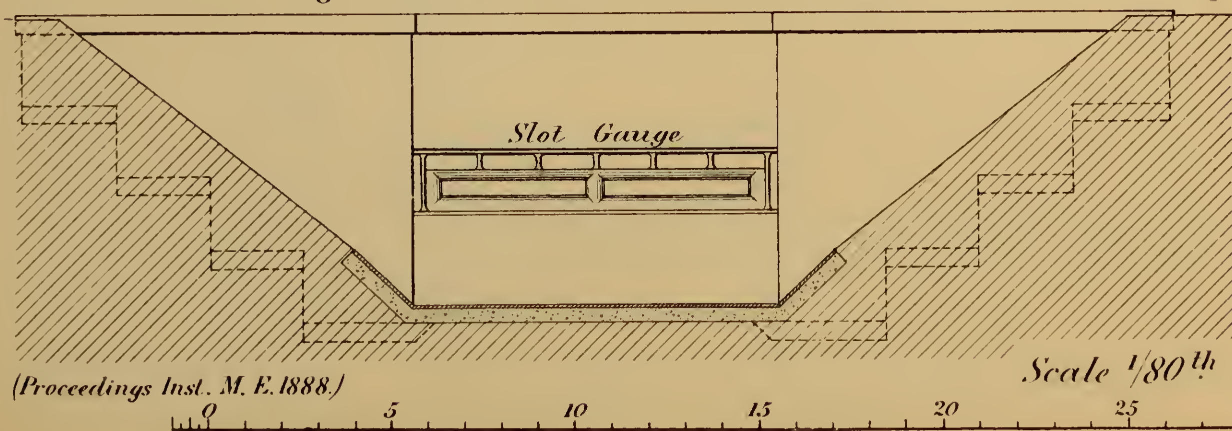
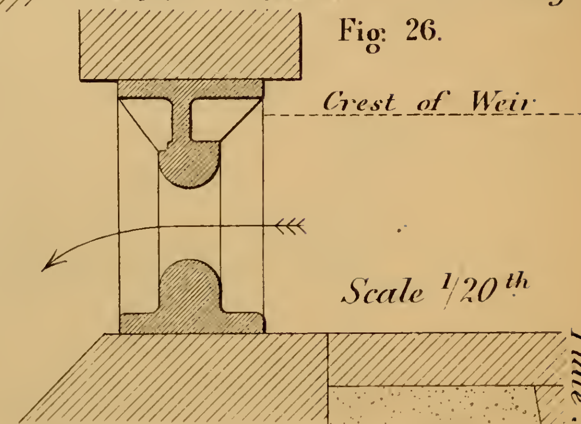


Fig. 25. Back Elevation of Slot Gauge.



Transverse Section of Slot Gauge. Fig. 26.



(Proceedings Inst. M. E. 1888.)

Plate 99.

RATHMINES WATER WORKS.

Plate 100.

Outlet Tower Upper Reservoir.

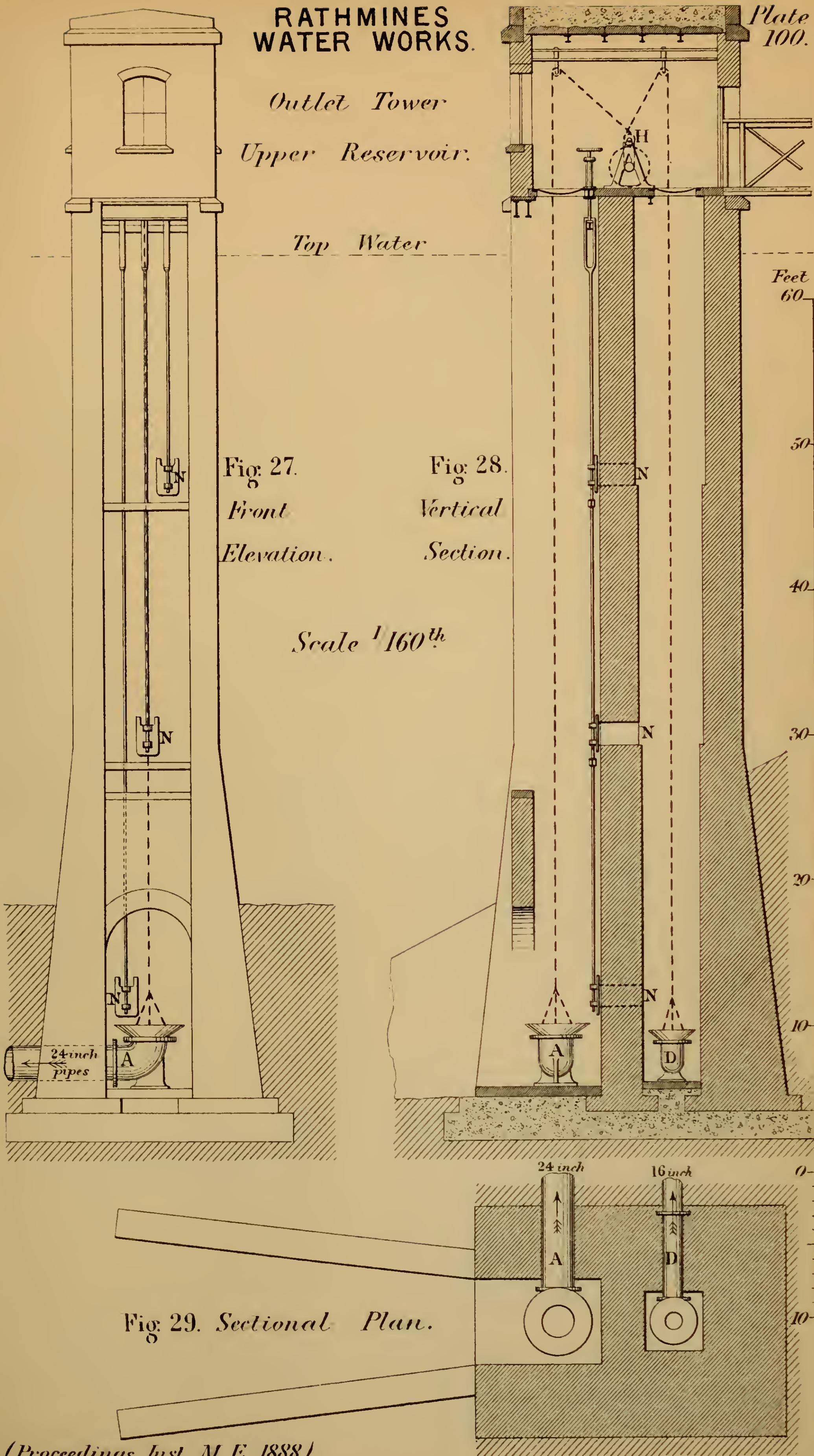


Fig. 27. *Front Elevation.*

Fig. 28. *Vertical Section.*

Fig. 29. *Sectional Plan.*

Scale 1/160th.

(Proceedings Inst. M. E. 1888.)

RATHMINES WATER WORKS.

Outlet Tower

Lower Reservoir.

Top Water

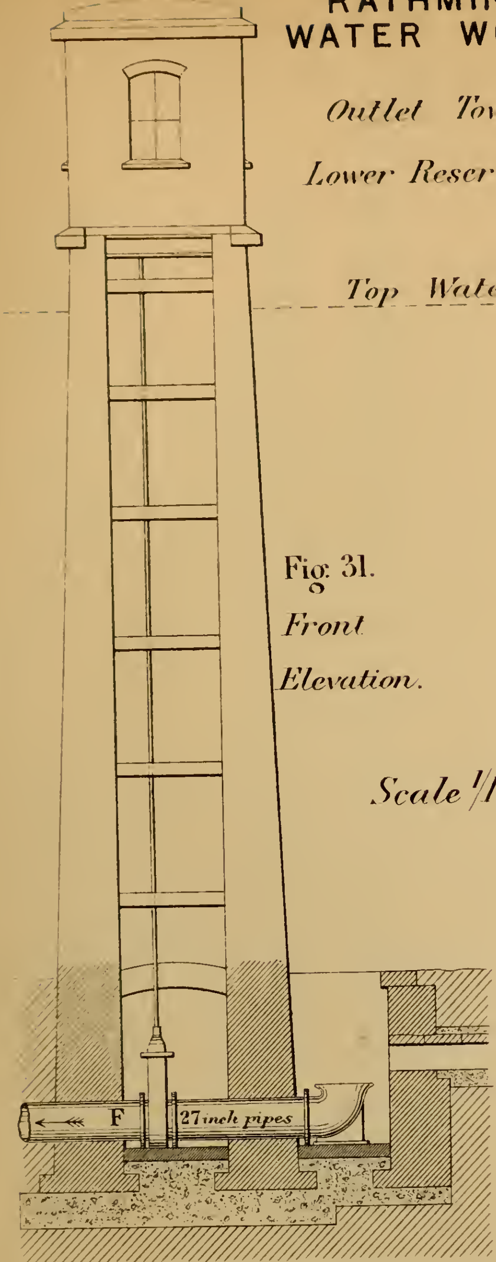


Fig. 31. *Front Elevation.*

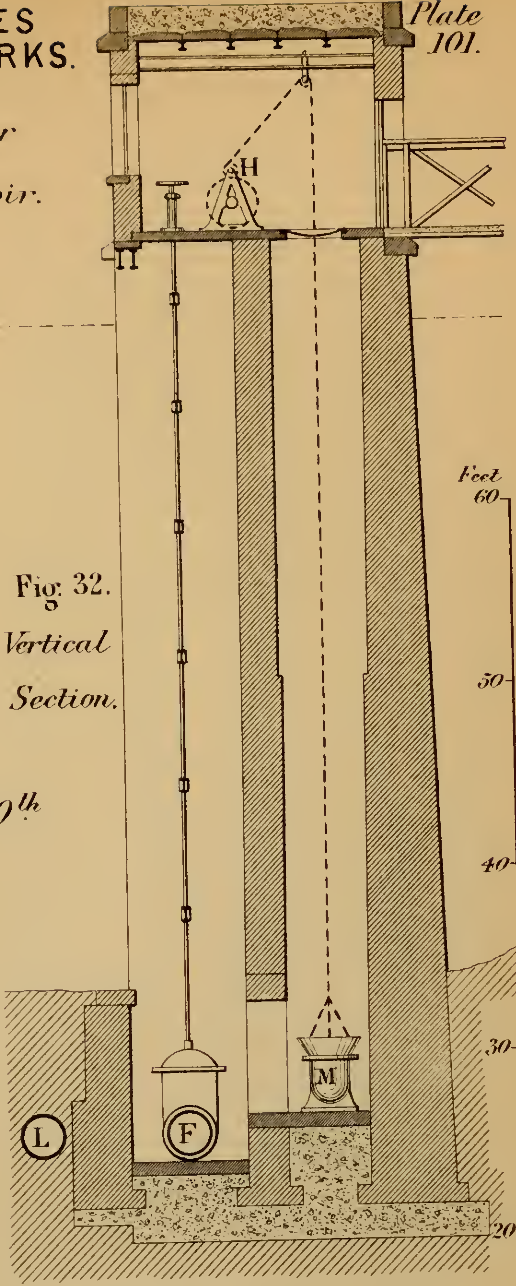


Fig. 32. *Vertical Section.*

Scale 1/160th.

Eduction Tunnel at Upper Reservoir:
Fig. 30. *Transverse Section.*

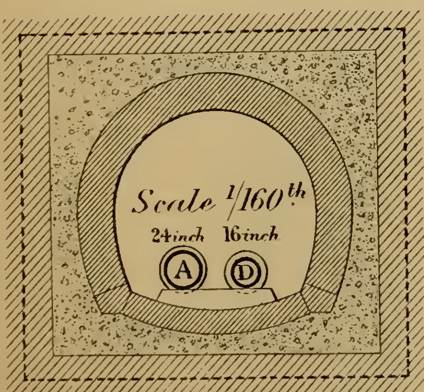
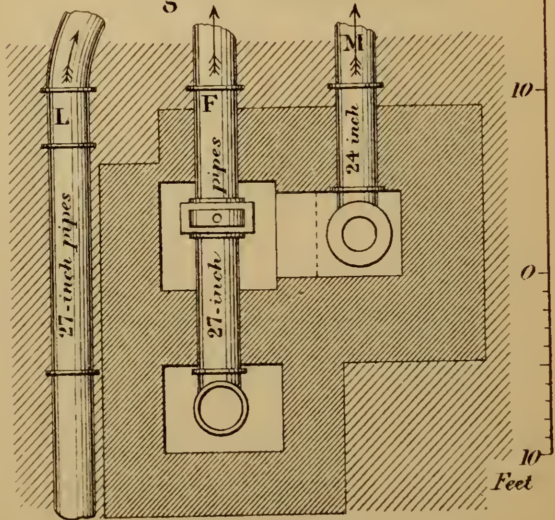


Fig. 33. *Sectional Plan.*



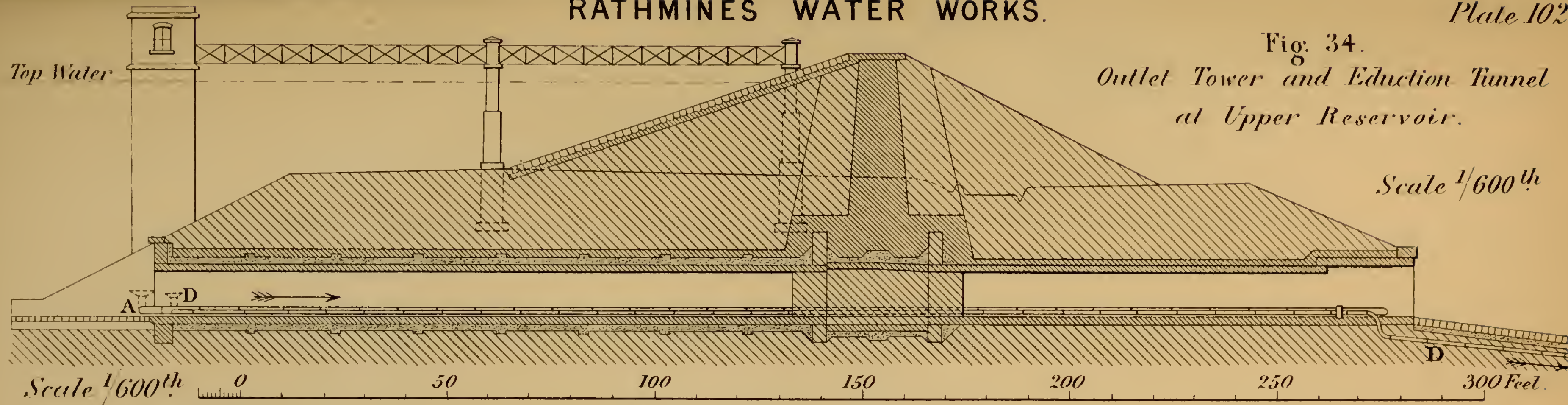
(Proceedings Inst. M. E. 1888.)

RATHMINES WATER WORKS.

Fig. 34.

Outlet Tower and Eduction Tunnel at Upper Reservoir.

Scale 1/600th.



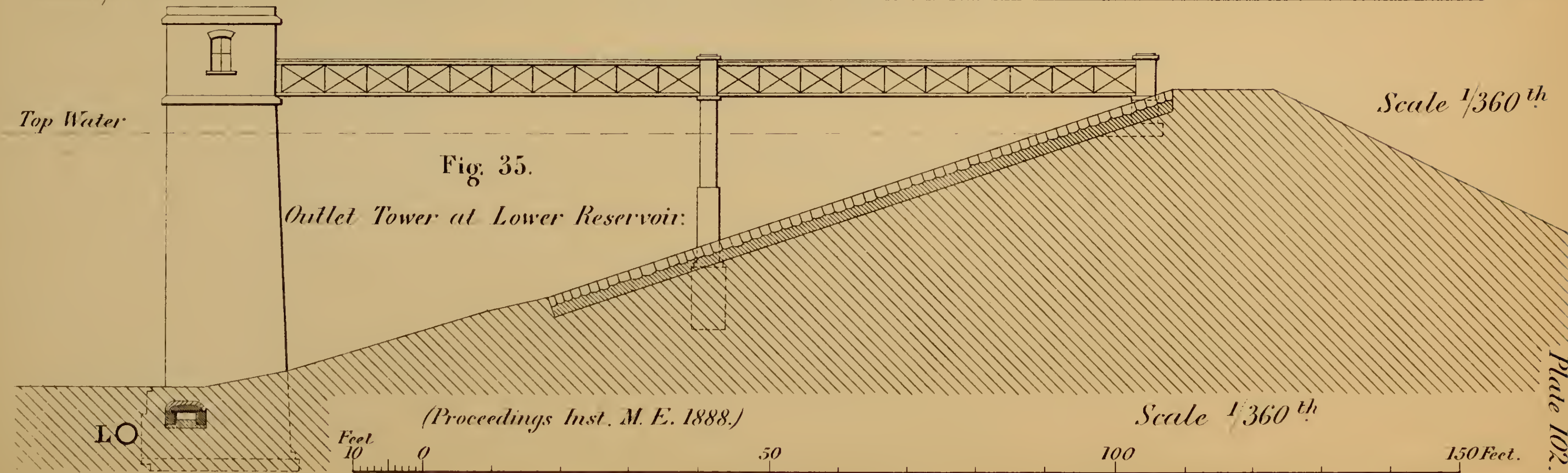


Fig. 35.

Outlet Tower at Lower Reservoir.

Scale 1/360th.

(Proceedings Inst. M. E. 1888.)

Scale 1/360th.

Plate 102.

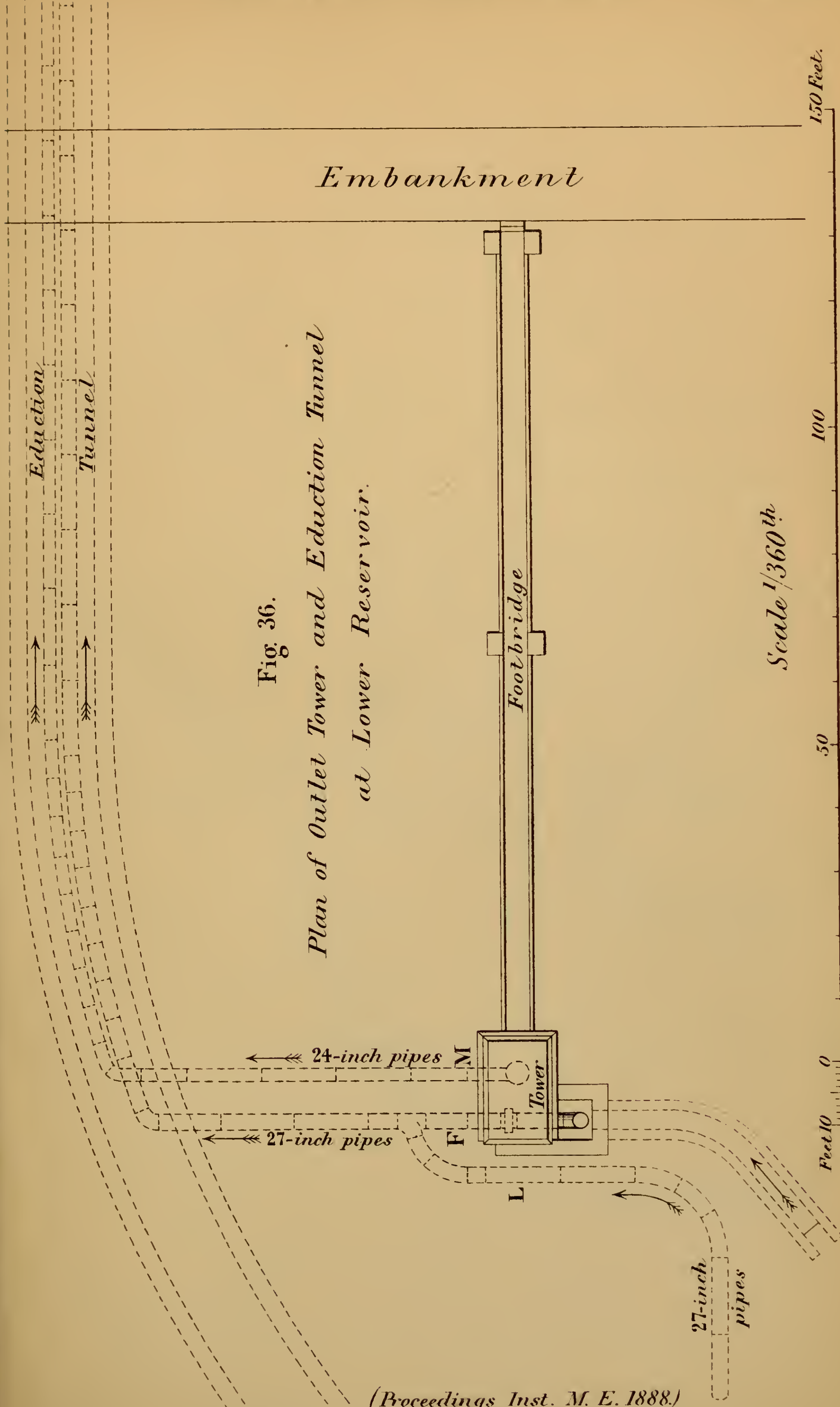
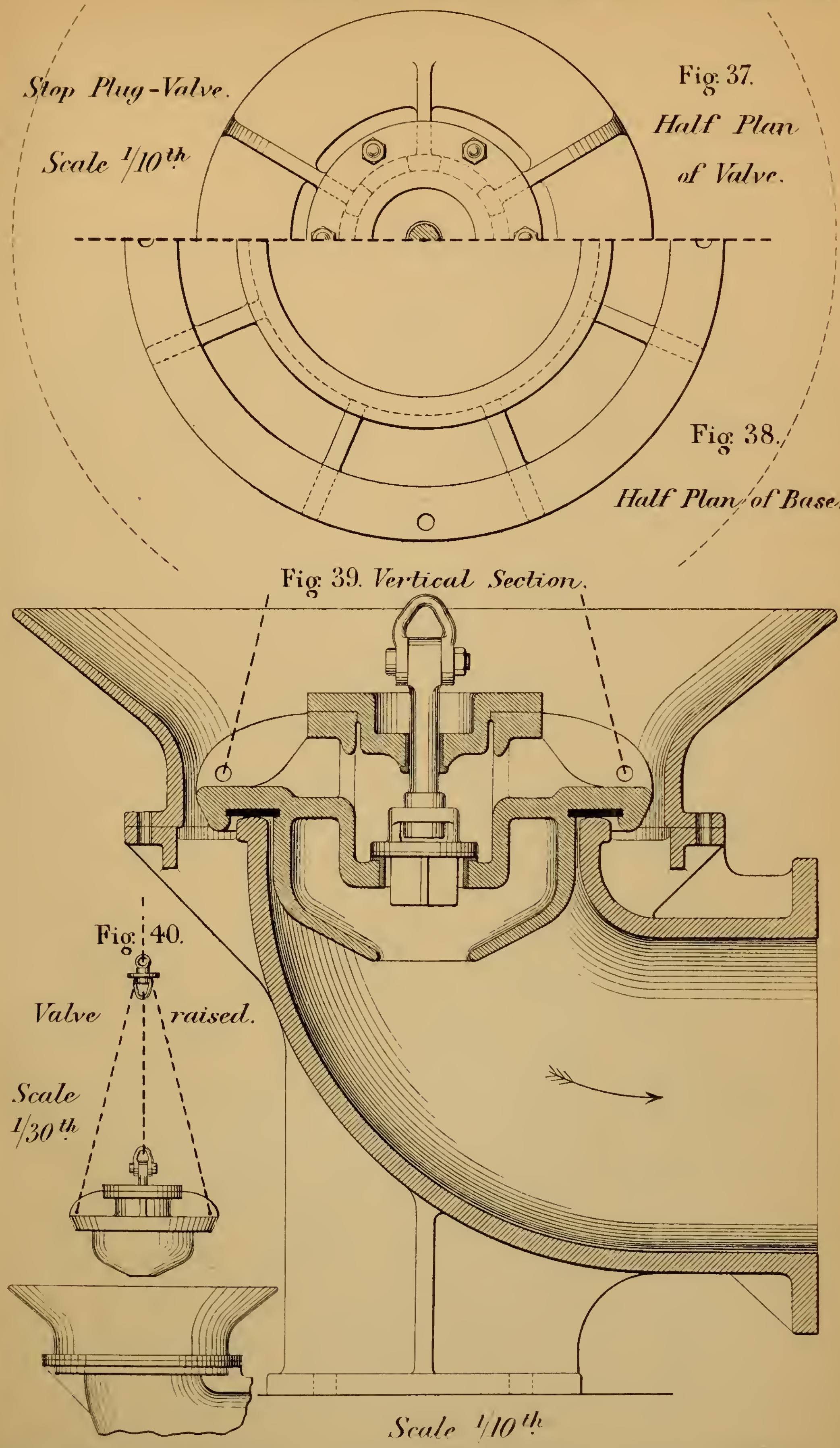


Fig. 36.

Plan of Outlet Tower and Eduction Tunnel at Lower Reservoir.

RATHMINES WATER WORKS. *Plate 104.*



(Proceedings Inst. M.E. 1888.)

RIVETED JOINTS.

See Table XXXIX.

A1 *to* A3, 13037-39; *and* B1 *to* B3, 13040-42.

Fig. 1.

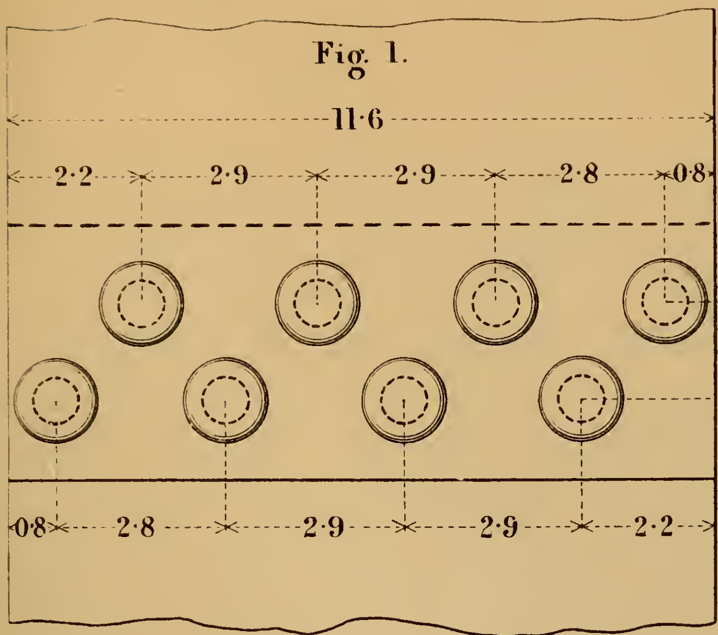


Fig. 2.

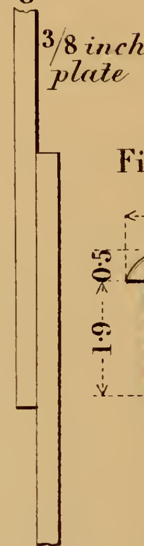


Fig. 3.

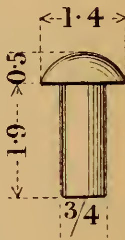


Fig. 4. C1 *to* C3, 13043-45.

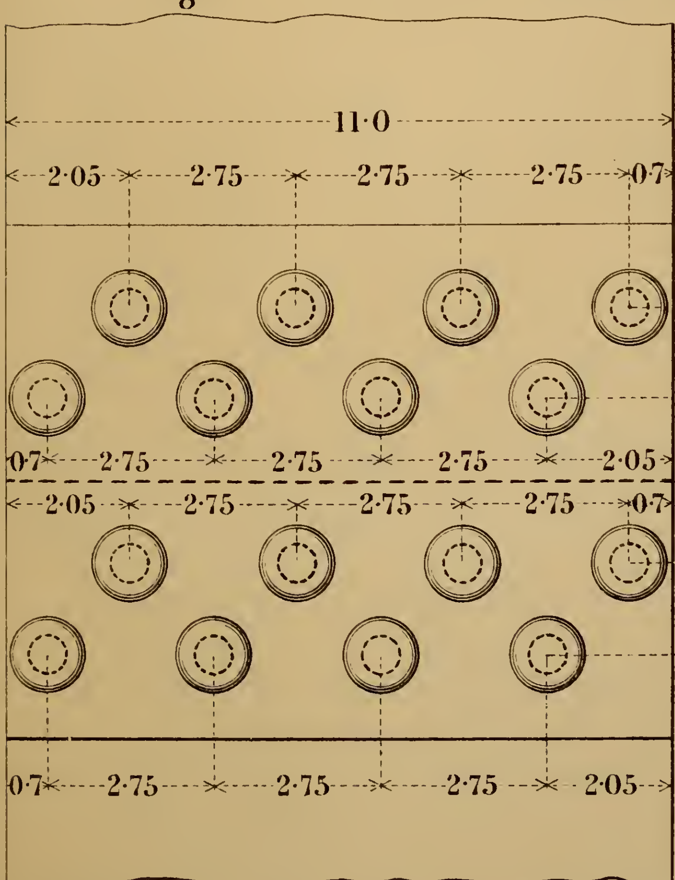


Fig. 5.

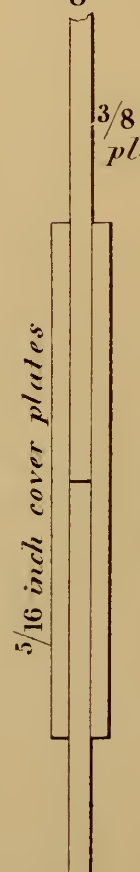
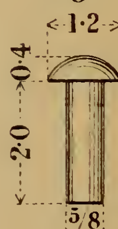


Fig. 6.



 Scale 1/4th *Dimensions in inches.*

RIVETED JOINTS.

Plate 106.

See Table XXXIX.

D1 *to* D3, 13046 – 48;
and
E1 *to* E3, 13049 – 51.

Fig. 9.

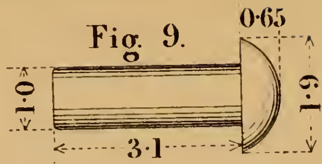


Fig. 7.

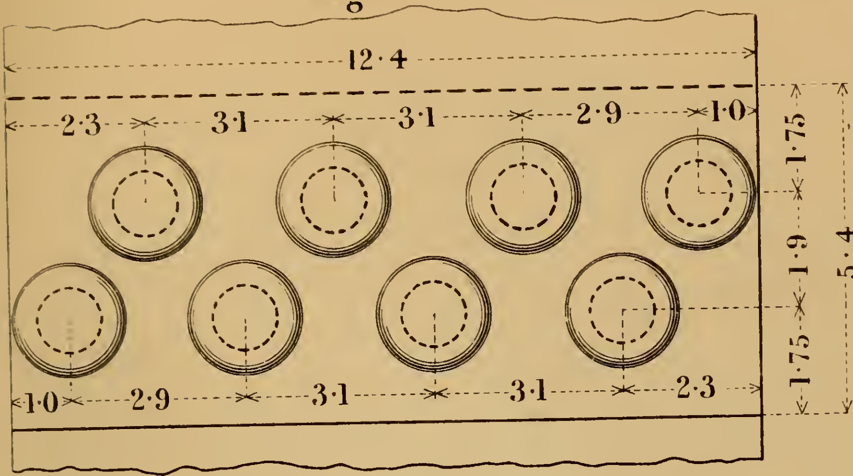


Fig. 8.

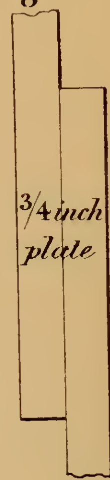


Fig. 10. F1 *to* F3, 13052 - 54.

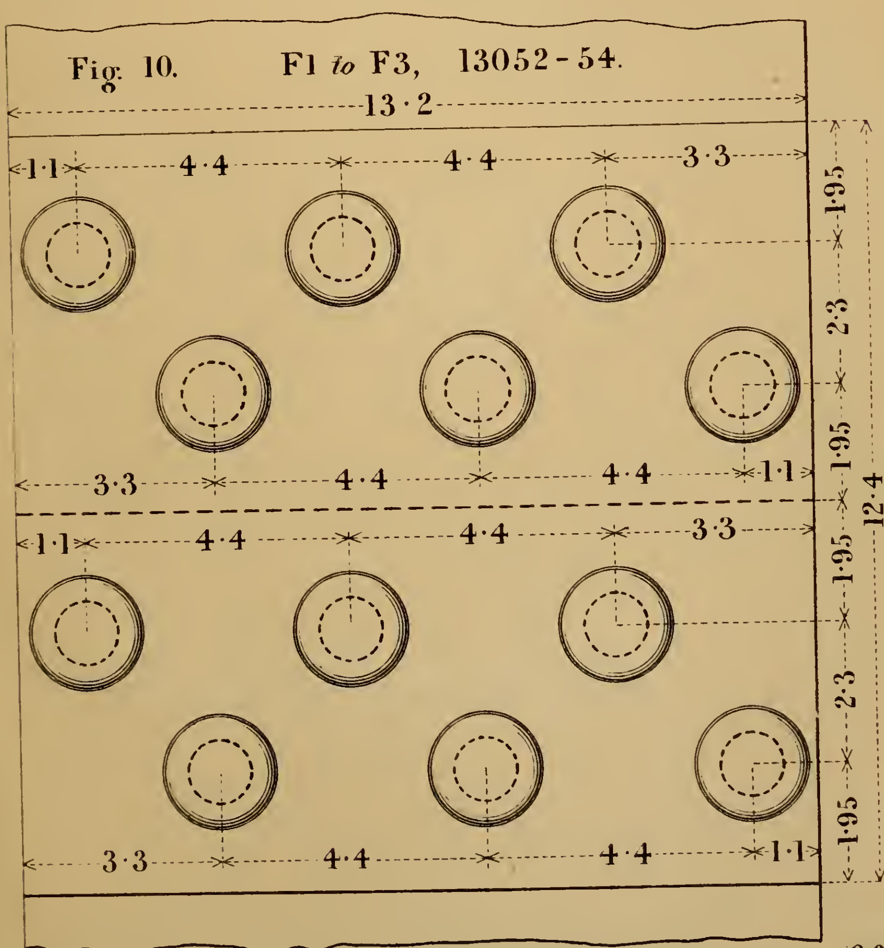


Fig. 11.

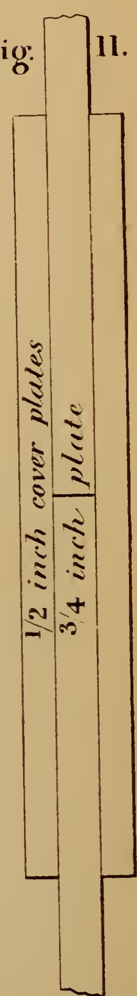
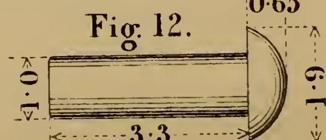


Fig. 12.



Scale 1/4th
Dimensions in inches.

(Proceedings Inst. M.E. 1888.)

See Table XL.

Fig. 13. G1 *to* G3, 13055 - 57.

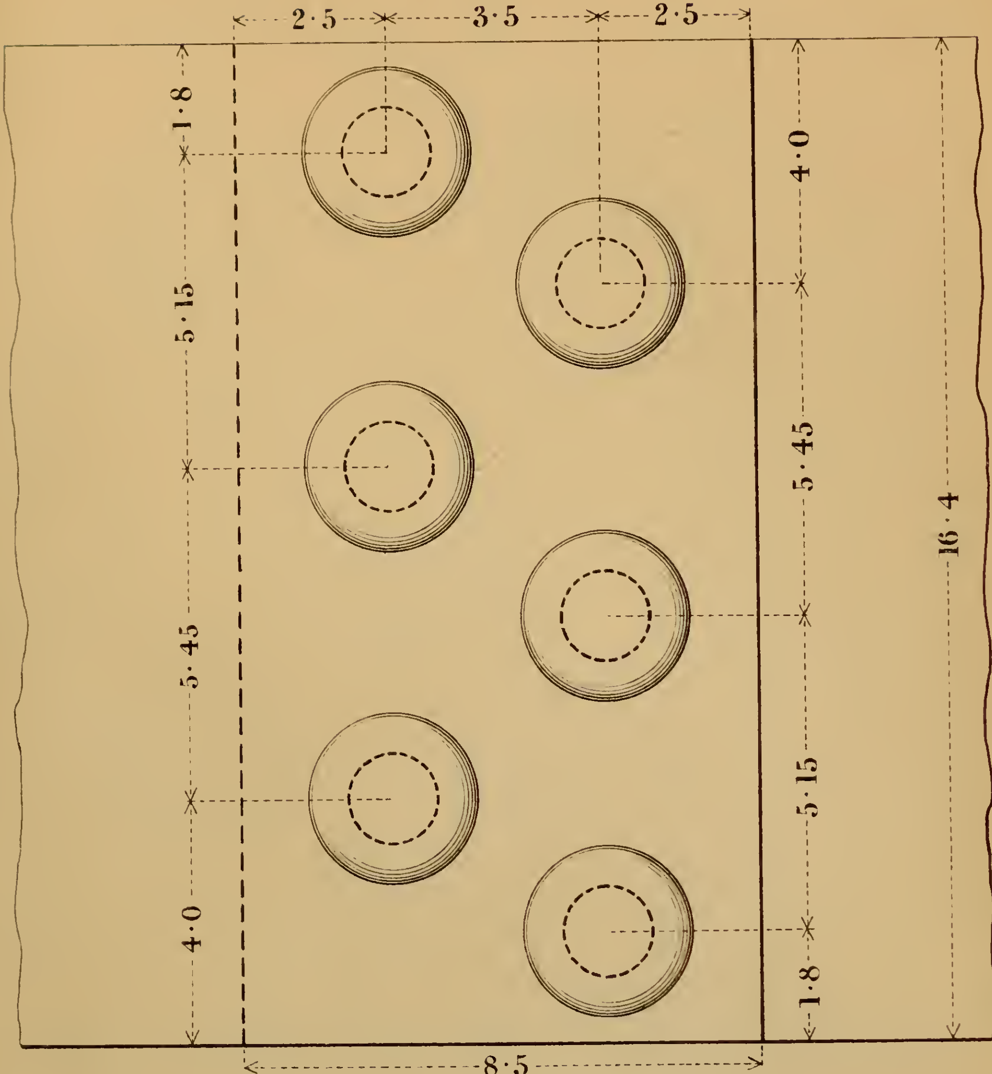


Fig. 14.

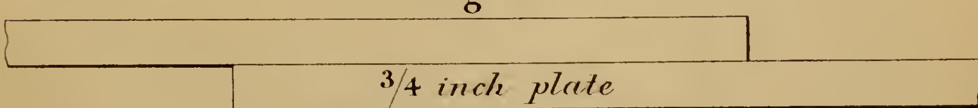
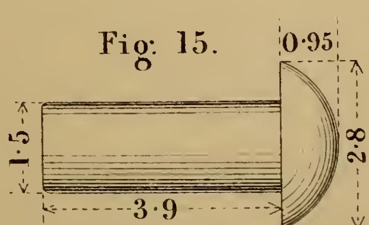


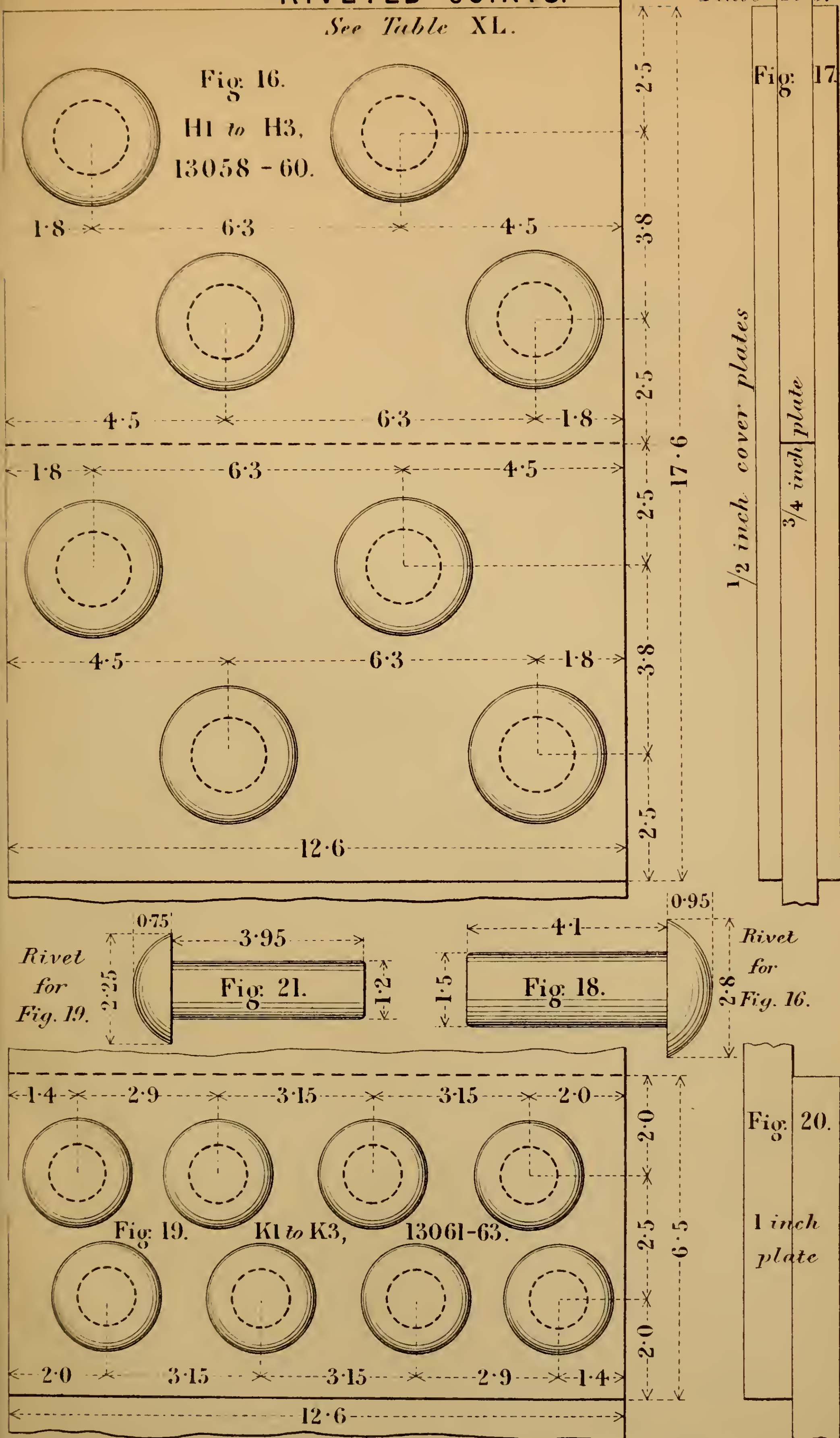
Fig. 15.



Scale 1/4 th

(Proceedings Inst. M. E. 1888.) *Dimensions in inches.*

RIVETED JOINTS.



(Proceedings Inst. M. E. 1888.) *Scale 1/4 th* *Dimensions in inches.*

See Table XL.

Fig. 22. L1 *to* L3, 13064 – 66.

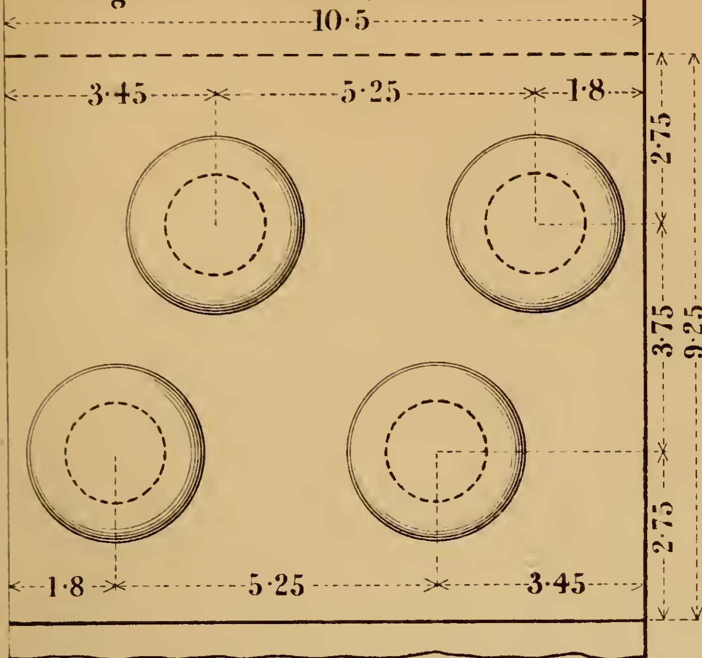


Fig. 23.

Fig. 24.

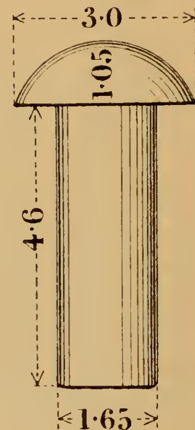


Fig. 25. M1 *to* M3, 13067 – 69.

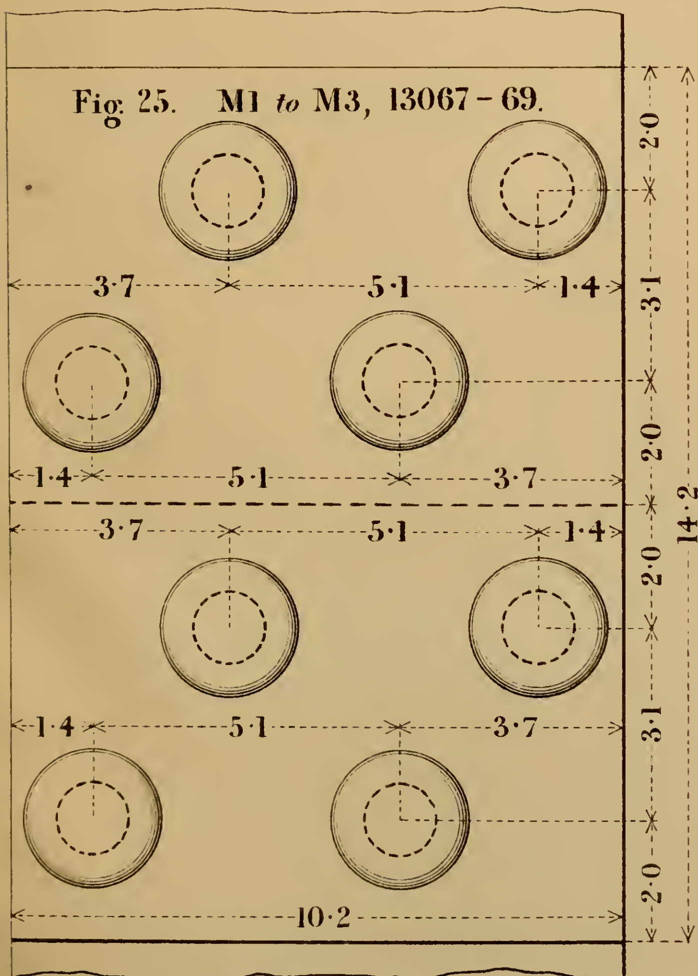


Fig. 26.

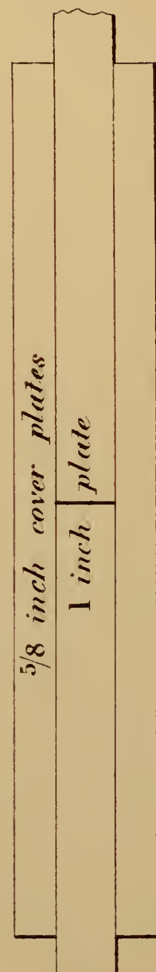


Fig. 27.